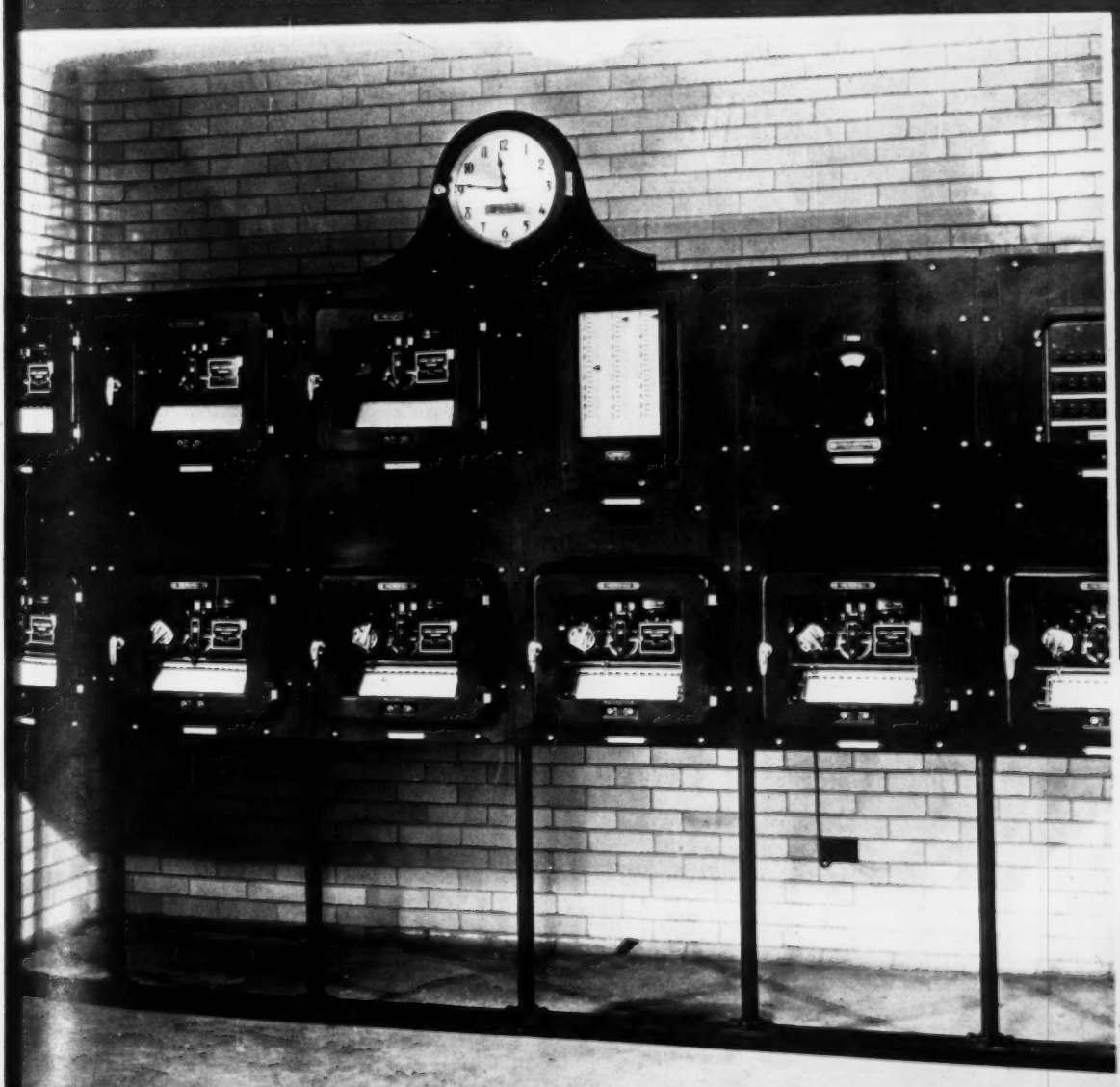
INSTRUMENTS

THE MAGAZINE OF MEASUREMENT and CONTROL



VOLUME 9

NOVEMBER

1936

NUMBER 11

DEVIATION HELD TO A MINIMUM . . .

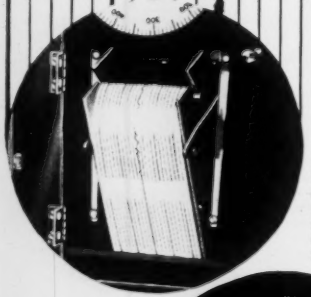
Recorded, and Returned to Control Setting . . by

STABILOG POTENTIOMETER

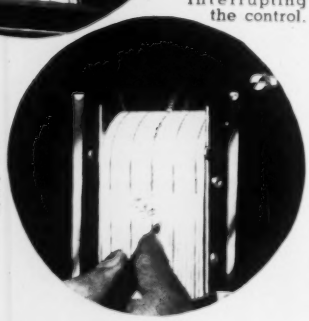
Here is a true record of temperature *control* of vapors leaving a vacuum tower refluxed with light gas oil. A temporary deviation from setting occurred following an unbalance of process conditions. The speed with which the Stabilog Potentiometer returned the temperature to control setting and the fact that the deviation was held to a minimum and quickly returned to setting is evidenced by the chart.

An exact record of *results* is thus provided . . . plus a record of deviation. It is a good example of "close control"—the capacity to maintain a pre-determined temperature with negligible deviation. The Stabilog Potentiometer gives you everything you need in control recording without sacrificing any inherent sensitivity. Recording does not affect the control action nor the measuring function in any way—and the 2-inch chart is inexpensive.

If you are interested in true low-cost recording of control deviations you will find the Stabilog Potentiometer an outstanding instrument for maintaining efficient operation of pipe stills, fractionating towers, and other similar equipment. New Bulletin 194-1 is yours for the asking.

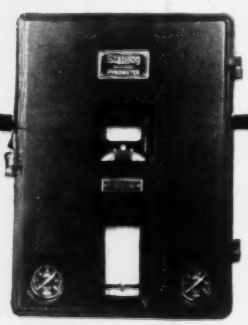


The chart can be changed and pen refilled without stopping the instrument or interrupting the control.



A writing platen under the chart gives a firm support for jotting down notes.

THE FOXBORO COMPANY
46 Neponset Avenue
Foxboro, Mass., U.S.A.
Branches in 25 Principal Cities



Foxboro Stabilog

REG. U.S. PAT. OFF.

ACCURACY FOXBORO *RESPONSE*

CORRECT INDUSTRIAL THERMOMETER

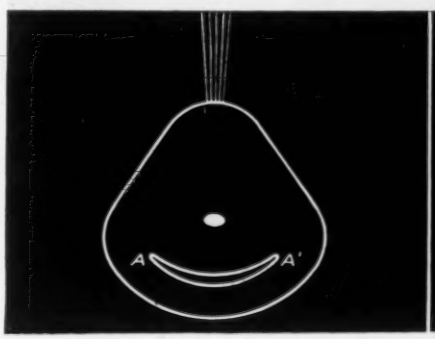
"BINOC"

eliminated, the separation between mercury-filled bore and empty bore is much clearer, and more accurate readings are possible.

Taylor "Binoc" Tubing has a triple lens construction (see cross-section drawing) which allows much more light to enter the tubing. With a greatly extended background (see cross-section) more light is concentrated and reflected back on the mercury column. It is three times easier to make correct readings.

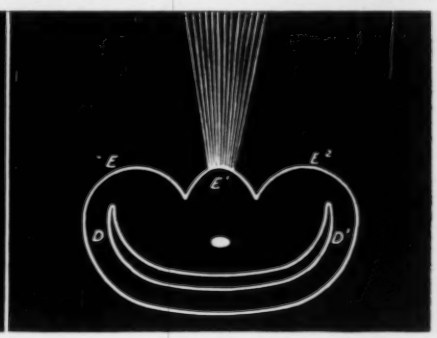
Let us demonstrate this remarkable new "Binoc" Tubing in new Taylor Industrial Thermometers. Test this wonderful new ease of reading and see its advantages for yourself. A Taylor Representative will give you all details. If you want quick information, send a wire or special delivery letter to Taylor Instrument Companies, Rochester, New York, or Toronto, Canada. Manufacturers in Great Britain—Short & Mason, Ltd., London, England.

PRESENT TYPE LENS TUBE

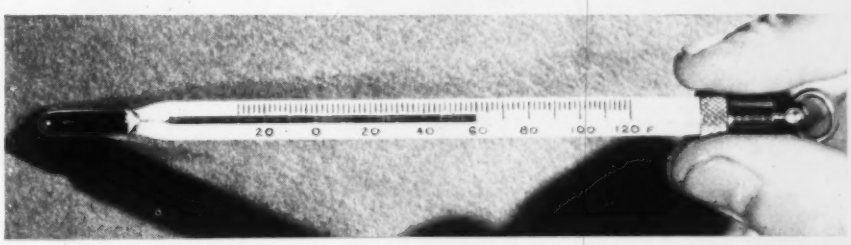


This is a cross section (looking down) of the usual Lens Tube used today. You can read this tube only by looking along one of the lines shown. The angle of vision is narrow. Small background (A-A¹) catches light only from directly in front. Bore reflection is present.

NEW "BINOC" TUBE WITH TRIPLE LENS



Cross section of the new Taylor "BINOC" Tubing. Note increased angle of vision. Also wider background (D-D') catching light rays from *three* lenses (E-E¹-E²). The reflected light is much stronger, the mercury column reading is much clearer. Bore reflection is eliminated.



TEST "BINOC" IN YOUR OWN THERMOMETER

BE ONE of the first to get this New Taylor Engineer's Pocket Test Thermometer with "BINOC" Tubing. It is offered to you to make your own easy-reading tests. You'll find it convenient to use in scores of places. Range: 0° to 220° F. or −30° to 120° F. Fill out coupon and order the range you want. Send check or money order.

TAYLOR INSTRUMENT COMPANIES,
Dept. H-2, Industrial Sales, Rochester, N. Y.

I want to see "BINOC" Tubing. I enclose check for the Engineer's Pocket Test Thermometers (with protective case).

CHECK HERE WITH RANGE −30° to 120° F—$1.25 EACH ☐
WITH RANGE 0° to 220° F—$1.50 EACH ☐

NAME_____

COMPANY AND TITLE_____

CITY_____ STATE_____

Taylor

INDUSTRIAL THERMOMETERS

with "BINOC" *tubing*

REG. U. S. PAT. OFF.

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Published Monthly on the 15th by
The Instruments Publishing Company
1117 Wolfendale Street Pittsburgh, Pa.

Branch offices
Boston: James Condon, 6 Marlboro St.
New York: Edwin F. Ripley, 118 E. 28th St.
Chicago: R. Farnham, 201 Wells St.
Glendale, Calif.: W. McIntyre, 1115 Tyler St.

Annual Subscription: U. S. $2.00. All other countries $3.00 *payable in advance* (remit by New York draft). Copyright 1936 by The Instruments Publishing Company. Entered as second-class matter January 26, 1932, at the post office at Pittsburgh, Pa. under the Act of March 3, 1879.

INSTRUMENTS The Magazine of MEASUREMENT and CONTROL

M. F. BEHAR
EDITOR

IN THIS ISSUE

As announced last month, the Q&A Department starts, and Problem No. 1 of the Forum is given.

So many of your recent questions have dealt with the use of photocells for measurements of light, color, turbidity, etc., that we deemed it best to have the world's highest authorities give you the definitive answers. It is a privilege to publish Dr. Gibson's discussion.

Ralph Batcher continues his chapter on fundamental applications of the cathode-ray oscillograph.

The chapter on oscillographs (of *all* types) in our electrical measurements handbook begins with a general introduction. Oscillography is a field in which Perry Borden has been active since 1910 when he ran tests which we believe helped make possible the effective illumination

of Niagara Falls. Anyway, this snapshot shows him using an oscillograph in the Province of Ontario—at Durham. He *was* young, handsome and British. Today he is American but otherwise hardly changed!

The front cover is thus described by John F. Heffelfinger, Engineer, Engineering & Construction Div., Public Service Dep't, City of Cleveland: "This control panel was installed to permit the superintendent to have complete knowledge of conditions in all furnaces day or night. Temperatures at 3 points in each furnace, and in each of the chimneys, are recorded. An indicator (upper right hand) checks the records for all points."

Our *Service* is Flexible, Our *Policy* Rigid

IN this rapidly-changing world, no periodical can long endure which does not frequently adapt itself to the changing needs of those whom it serves. Ever to give you, through the varied contents of each successive issue, the kind of service you need at the time—not the kind of service you needed two or ten years before—such is our constant endeavor, but in large measure it is you who make this possible, by frequently sending in questions and suggestions—by treating *Instruments* as if it were a service department in your own organization. We need not ask you to keep on sending in questions (these pour in), but we must ask you to send in more comments. Absence of criticism is flattering—not because it indicates that you consider *Instruments* perfect in its present arrangement and contents, but because it implies that you have confidence in our ability to anticipate your coming needs, to plan ahead and to make changes when needed.

What you evidently *don't* want us to change is our editorial policy—particularly the conduct of the "New Instruments" Department, as previously set forth on this page in unmistakable terms:

> *Instruments'* news pages are not for sale . . . The "New Instruments" Department is not controlled by advertisers . . . As if their appropriations could buy a single inch of our news space! . . . Since the news space is not for sale, we guard its high standard by wielding a blue pencil consecrated to the service of our readers.
>
> Here's where we lift the veil: If one manufacturer sends us a 2000-word description of a mere new model, we may boil it down to one brief paragraph; while if a second manufacturer brings out something wholly new but sends us only a one-paragraph announcement, we urge him to prepare an adequate engineering description.
>
> To put all new products through examinations and tests, and print full engineering reports on design, construction and performance, would require facilities like those of the National Bureau of Standards or Underwriters' Laboratories; and one result would be a 400-page magazine you wouldn't have time to read!
>
> On several occasions we investigated new instruments and wrote them up without consulting the makers' bulletins. It even has happened that we discovered and printed facts which the makers did not know.
>
> *Instruments* has been fortunate in establishing relations with instrument company physicists and other technical men. We sometimes get exclusive technical descriptions of new products, conservatively written for *you* by these modest specialists.

This policy remains unmodified and inflexible. And the instrument companies—be it said to their credit—respect The Instruments Publishing Company's scrupulous separation of its editorial and business departments. Proof of their respect came to your editor's notice as he was making up this issue and observed that the advertising space sets a new record. Virtue has its tangible as well as moral rewards!

INSTRUMENTS' READERS AT WORK

No. 19—GILBERT C. STAUFFER

Assistant Manager, Technical Department
Driver-Harris Co., Harrison, N. J.

By M. F. BEHAR

IT would take an expert metallurgist to write intelligently about Stauffer's years of work on special alloys for electrical and other technical purposes; or at least a writer who isn't awe struck by these mysterious alloys, as we confess we've been ever since we mussed up the attic of our boyhood home with thermocouples and electrodes bearing fearfully scientific names. Yes, we were afraid to interview Stauffer, because "Driver-Harris" means "Nichrome," "Advance," Manganin and other mysteries of metallurgical science. Stauffer is directly responsible for the *production* of instrument alloys—a subject of which we are pitifully ignorant. To our delight and relief, we found him to be responsible also for *quality*. This means, of course, the determination of measurable properties, by means of more or less familiar instruments. As the D-H alloys are used largely by the electrical industry, electrical constants are of prime importance, but it happens that many of these alloys are heat and corrosion-resisting as well. The Inspection Department therefore has splendid facilities for physical tests as well as for electrical determinations. We suggested to Stauffer a scheme of listing his instruments on this page, but he made up his own, which gives you an excellent idea not only of his quality-control work but of his own orderly mind.

Though born in Wellsboro, Pa. (1894), Stauffer has lived in Newark, N. J., and vicinity since he was thirteen. After graduating from the Newark Academy he attended Stevens Tech for two years, transferred to Lafayette and—war having come—left to enter the Heavy Artillery School at Fortress Monroe, Va. As a Lieutenant he served with the 42nd C.A.C. in the A.E.F. In 1919 he resigned from the Army to join his present employer. Seventeen years' work on special alloys! Do you wonder we stood in awe of his accomplishments? Well, it turned out that his hobby is gardening, that he has a wife and two children, that he belongs to the A.S.M., to 'ST2 Stevens Chapter, and that he likes instruments and *Instruments*.

In the background of the snapshot below, you can dimly see galvanometers nested in anti-vibration suspensions which, if your memory, your eyes (and the printing) are good, you will recognize as "Brevoort" rather than "Julius" suspensions.

Now, then, it was in the May 1931 *Instruments* that Dr. Brevoort told how he licked the galvanometer vibration problem at the Bureau of Mines' Amarillo station.

So what? So it proves that Stauffer is not only an old subscriber but an alert one, carrying out the ideas he finds in *Instruments*.

INSTRUMENTATION FOR CONTROL OF QUALITY THROUGH INSPECTION DEPT

A—ELECTRICAL MEASUREMENTS

(1) Resistance

Portable Wheatstone Bridges	24
Portable Kelvin Bridges	4
Laboratory Type Kelvin Bridges	2

(2) Temperature Coefficients

Variable-ratio Wheatstone Bridge	1
Mueller Thermometer Bridge	1

(3) Thermal e.m.f.

L&N Type K Potentiometers	2

(4) Dielectric Strength of Insulation

High Voltage Tester	1
Low Voltage Tester	4

(5) Life Testing on Resistance Wires

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(6) General-purpose and Accessory

Galvanometers, Oil baths, Furnaces, Controllers, etc.

B—PHYSICAL PROPERTIES

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(2) Hardness Tests

Rockwell Hardness Testers	2
Superficial Hardness Testers	1
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Erickson Testers	2
Brinell Testers	1
Scleroscope	1
Deflection Testers (various types)	6

(3) Linear Expansion

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Filar Micrometer	1
Projection Microscope	1
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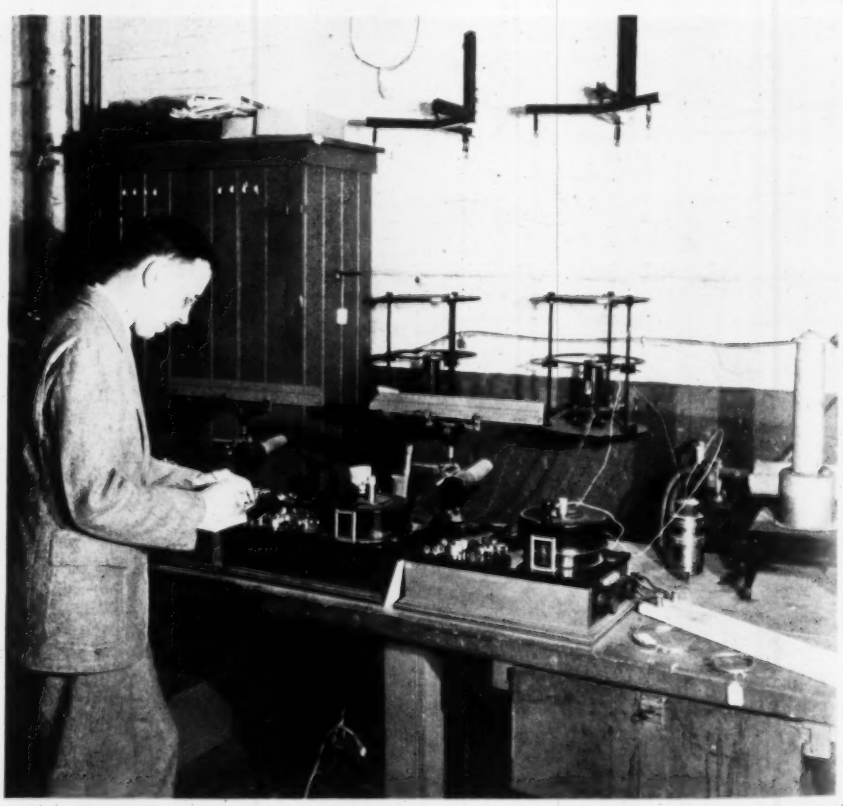


HE MONTH'S NEW INSTRUMENTS

In this department we strive to report each month ALL the new devices for measurement, inspection, testing, metering and automatic control—in the form of concise technical descriptions.

When writing to manufacturers directly, please mention this department as your source of information.

Or write to Information Section, Instruments Publishing Company.

Neon-tube Oscilloscope

In this new electronic device known as the "Neobeam Oscilloscope" a gaseous discharge tube is employed to make visible the wave pattern under investigation, the pressure in the tube being such that

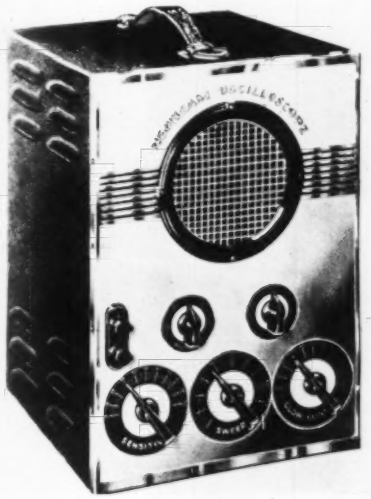


Fig. 1

the area of the glow covering the cathode is proportional to the current passing through the tube. On alternating current, the electrodes glow alternately. Both being elongated, the lengths of the glowing portions are proportional to the instantaneous currents. The image of the tube being reflected from a revolving mirror with axis parallel to the tube axis, the wave form appears as shown in Fig. 2, the dark space between its two halves being the space between the tips of the two electrodes in the tube. This tube measures 6" overall by $1\frac{1}{2}$" diam. and is filled with purified neon. The two electrodes, each 2" long by $\frac{3}{16}$" diam., are set at each end of the tube so as to develop a 4" image. The ignition potential of 200 volts is supplied from a power generator, made up with a 6L6

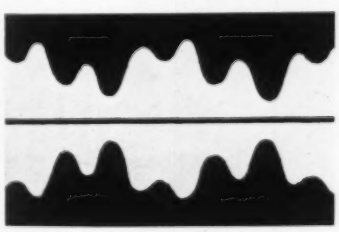
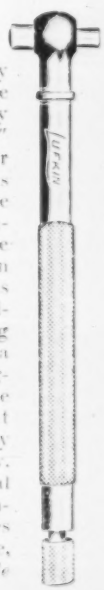


Fig. 2

Beam Power Tube as a 100 kc. r-f. oscillator feeding directly into the neon oscilloscope tube to keep a constant glow on the tips of the electrodes. The input potentials are amplified by a 6J7 and 6L6 high-gain audio amplifier and impressed on the power generator. The revolving-mirror sweep is controlled with a Vari-Speed motor unit calibrated in r.p.m.—a direct-reading feature permitting frequency determinations. One microvolt input is sufficient to produce full-scale deflections of the image on the 4" calibrated screen. Thus, 12" of bare copper wire (attached to end of shielded cable connected to input terminals) provides sufficient pick-up to "indicate a 60-cycle line five feet away." The unit measures $8\frac{3}{4}$" × 10" × 13" high and weighs 25 lbs. Panel has an etched chrome finish; cabinet is finished in black crackle and is fitted with a leather handle. For demonstrations of a-c. phenomena, sound, pitch, timbre, frequency, and wave-form, a special high-fidelity crystal microphone is supplied to connect directly to the input terminals without the use of a pre-amplifier. A speaker is provided also to connect directly to the output of the amplifier so as to produce the identical sound that is presented on the screen. Radio laboratory applications include checking modulation, amplifier fidelity, hum tracing, distortion, gain measurements, and receiver sensitivity and response. The amplifier unit can serve also as a portable power amplifier system or modulator for a small transmitter. The manufacturer uses the Neobeam Oscilloscope for production tests, electrical balancing, motor and phase load study, and general laboratory work. With reasonable care, an image may be photographed. *Sandt Engineering Company, 4250 Lincoln Ave., Chicago, Ill.*

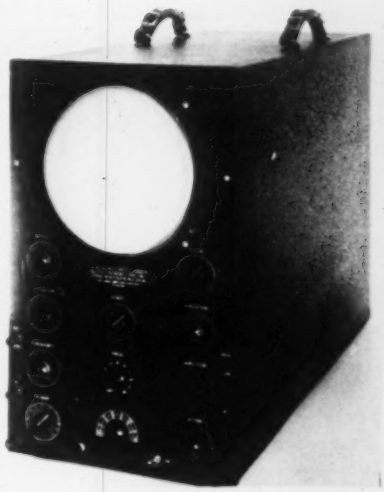
Telescoping Gage



What is said to be the very real need for a telescoping gage to measure under $\frac{1}{2}$" is met by new "No. 79AA," range $\frac{3}{8}$" to $\frac{1}{2}$". As in maker's larger gages, the handle can always be locked in the center of the plungers. This distinctive feature is said to permit the tool to enter and operate in small and slotted openings. This new "No. 79AA" being an addition to a line of telescoping gages, consists like those of a knurled handle and two plungers, one telescoping into the other, both under constant spring tension and locked by slight turn of knurled screw. Maker announces also several sets of gages, the most complete set consisting of six gages and covering the entire range, $\frac{3}{8}$" to 6". *The Lufkin Rule Co., Saginaw, Mich.*

Cathode-ray Oscillograph

Including a 9" tube, but portable, "Type 158" cathode-ray oscillograph is designed for laboratory work or lecturing. It is the complete combination of all the features incorporated in maker's



other oscillograph units. The consequent completeness of this unit, as well as the unusually large tube, are said to make exact wave analyses possible. Because of the high voltages used, the trace is so brilliant that it may be readily observed in daylight at a distance of 40 ft. There are two power supplies, one of high voltage for the cathode-ray tube and another of low voltage for the operation of the amplifiers and linear sweep circuit. It is possible to vary the high voltage power supply in 500-volt steps from 1500 to 3000 volts. The high anode voltage permits the use of a tube with time delay or high-speed photographic screen. The sweep circuit, said to be exceptionally linear, allows the observation of waves from 10 to 500,000 cps. It is possible also to synchronize fractions as well as multiples of the waves under inspection. All necessary controls are on the front panel. By means of a single control knob it is possible to apply signals and sweep voltages to the deflection plates in various combinations. This unit is completely a-c. operated from 110-120 volt mains and has a power consumption of 80 watts. *Allen B. DuMont Laboratories, Inc., Upper Montclair, N. J.*

Cathode-ray Tubes

A new line of cathode-ray tubes has been brought out, the three models being the 31-XH, 54-XH and 91-S-H; with 3", 5" and 9" screens respectively. By reason of an improved electron gun structure and the addition of a collector electrode between the deflection plates and the screen, these tubes are said to be characterized by hair-line trace, uniform focus over entire screen, good brilliancy, substantially increased sensitivity, and longer service life. *Allen B. DuMont Laboratories, Inc., Upper Montclair, N. J.*

BAILEY METER
CONTROL SYSTEM

The Mark of

Effective Control

Process Control for sensitive, stable automatic control of temperature, pressure, liquid level, flow and other factors as applied to industrial processes. Responds to changes quickly, without overtravel or hunting. Ask for Bulletin No. 101.

Combustion Control that is simple but *complete* for providing economical operation of boilers of 200 h. p. and larger. Details in Bulletin No. 102.

Recorder-Controller

Boiler Meters for recording combustion conditions and guiding boiler operators. Described in Bulletin No. 44.

Multi-Pointer Gages for indicating factors such as draft, pressure, temperature and speed. These Gages are available with any number of pointers and any scale combination; in either the oil sealed bell or diaphragm construction.

Control Drive

Flow Meters for indicating, recording and integrating the flow of steam, water, sewage, air, gas and other fluids. Bulletins No. 39 and 300.

Recorders for pressure, temperature, drafts, liquid level and other factors.

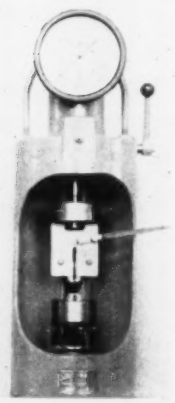
G-3

BAILEY METER COMPANY

1041 Ivanhoe Rd., Cleveland, Ohio

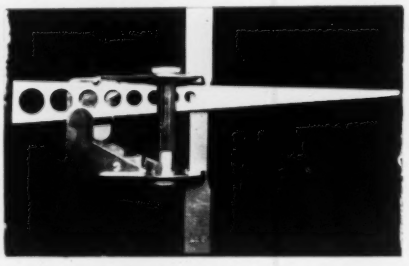
Spot Weld Testing Machine

Primarily intended for accurately testing the strength of spot welds but applicable to general tensile testing <10,000 lbs., the Southwark Spot Weld Tester can be rolled from place to place and is also provided with a hoisting hook for moving with a crane. Its overall height of 70", 18" diam. steel base, low center of gravity, and weight of approx. 800 lbs. are said to make it "ideal for portable service." An 8" dial indicates the load. The cylinder, located at top of machine, has a 4½" diam. ram with a 2" stroke. Fluid pressure is supplied by a gear pump in the base, direct connected to a ¼ h.p. motor. Self aligning, lever operated grips are so designed that hard, sharp faces can be quickly installed at low cost, being made of short sections of machine-cut files. Upper grip is of open-face type; lower grip is of closed type with wide-angle entrance. These grips will accommodate offsets in welded specimens from the smallest gage to ¼" thick without using backing plates or liners. Specimens up to 1¼" wide can be tested. Diamond-grip holders are cut from solid blocks of high-carbon steel. Top and bottom handling levers are set at right angles to permit convenient operation. All working parts are accessible by removing front cover plate. — *Baldwin-Southwark Corp., Paschall Sta., Philadelphia, Pa.*



Extensometer

Marking of gage points on the specimen is unnecessary when using the Kenyon-Burns-Young Extensometer. This new device is a 2" gage length extensometer of extremely light construction whose hardened gage points clasp the test specimen with pressure derived from coil springs. The frame is made in two distinct halves, one telescoping into the other. A wedge passes through a slit in this frame which widens by reason of separation of the two halves as the specimen stretches, thus permitting the wedge to pass farther through the slit until the specimen fractures, when the two halves part, each clinging to a part of the broken specimen and letting the wedge pass all the way through. The wedge is urged through the slit by means of a weight hanging over a pulley at the end of a tension cord. This cord turns the drum of a load-deformation recorder or moves the stylus across the recorder drum in accordance with the particular design of the recorder itself. The [illegible] of the wedge determines the magnification of deformation as recorded on the drum—the steeper the slope the less the magnification. Device is built under license from the American Rolling Mill Co. — *Baldwin-Southwark Corp., Paschall Sta., Philadelphia, Pa.*

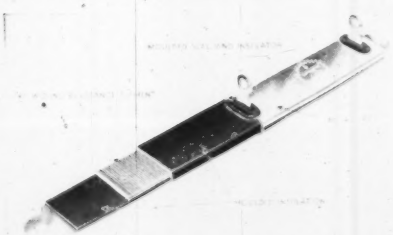


Oscillator-and-Multimeter

"Model 540-740" direct-reading signal generator and volt-ohm-milliammeter, a new "Ranger-Examiner" combination, includes in one case two units of test equipment for use of service men. The "540" signal generator unit has plug-in type coils for the five frequency bands from 110 to 20,000 kc. All readings are direct. Each coil is individually calibrated by peaking with trimmer condensers. Accuracy is within 1% from 110 to 3,000 kc., 2% for higher frequencies. The "740" volt-ohm-milliammeter unit has a 3" Triplett instrument with scale reading: 10-50-250-500-1000 d-c. and a-c. volts at 1000 ohms per volt; 1-10-50-250 d-c. milliamps; low ohms, 0-300; high ohms to 250,000 at 1.5 volts. (Provisions for higher resistance readings to 2.5 megohms by adding 135 volts of external batteries.) Combination metal case measures 11⅞" × 7½" × 4½", with compartments for accessories. — *Readrite Meter Works, Bluffton, Ohio*

Molded-seal Armored Resistors

Hermetic sealing provides protection against humidity and electrical leakage in new "Series MR" wire-wound metal-clad resistors; and continuous contact between winding core and Bakelite molded insulation, plus a snugly fitted metal jacket clamped flush against the metal chassis, are said to provide maximum heat dissipation. Resistance element is fully imbedded so that turns cannot slip. Units are rated at 5 watts per winding inch when mounted flush on metal radiating surface; safe overload of 100%; in free air, 2½ watts per winding inch. Available in wide range of resistance values, any number of taps, sizes up to 10" × 1⅜" × ¼". — *Clarostat Mfg. Co., Inc., 285 N. Sixth St., Brooklyn, N. Y.*



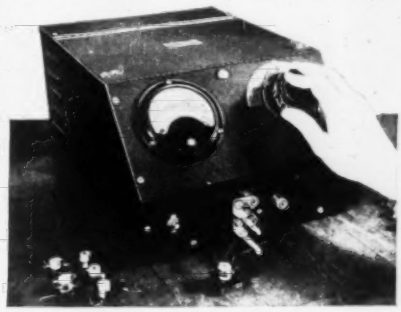
Research Metallographic Outfit

Including complete equipment for work with bright field polarized light, and dark field, a new research metallographic outfit has a magnifying range from a low limit of 2.5× to the highest magnification possible with oil-immersion objective and high-power eyepieces. Equipment consists of the inverted microscope units; high-intensity illuminating system with either a motor-driven arc lamp and resistance for d-c. use or tungsten arc lamp for a-c. use; 8" × 10" camera, with metal front and rear supports, carried on a bar graduated to give bellows reading directly; supporting bed carrying extension focusing rods on either side for coarse and fine adjustment of microscope; new stand with adjustable shock absorbers; large cabinet for accessories and plate holders and adjustable-height cushioned stool.

Circular stage is of revolving type, 6" in diam. to give smooth movement, with circumference graduated in degrees. (A lock can be provided to stop rotation when desired.) Top plate of stage is adjustable by a mechanical movement 1" in each of two mutually perpendicular directions, permitting rotation of specimen on center which coincides with field of objective. New type vertical illuminator serves not only for bright-field work but as an analyzer and polarizer for polarized-light work. Its efficiency (amount of initial illumination transmitted to object) is said to be several times that secured with conventional clear-glass or prism type illuminator. Different degrees of polarization of the light beam are secured by the rotation of a quarter-wave plate near the Nicol prism used in vertical illuminator. Dark-field illuminator is a glass cube with central stop mounted in a rotating turret with the vertical illuminator prism. This permits rapid change from bright-field or polarized-light to dark-field without disturbing focus of objective. Two dark-field condensers, supplied for use with different power objectives, mount directly beneath stage of microscope. A battery of six objectives and ten eyepieces gives full range of standard magnifications for metallographic work. Objective holder is of quick-change type, centerable with clamp for positive positioning of objective. An entirely new photomicrographic lamp has been developed by makers to give an intensity approx. 2½ times that of any existing concentrated homogeneous light-source. Beneath top of supporting stand are located the shock-absorbing devices; outfit can be supported on the shock absorbers or lifted off by adjusting levers under top portion of the supporting legs. Adjustable dampening devices regulate tension on spring support. In supporting legs are the housing, the resistance, adjustable ammeter for arc lamp and transformer for Mazda lamp. A two-drawer cabinet in right end of table accommodates accessories and plate holders. — *Bausch & Lomb Optical Co., Rochester, N. Y.*

"QX-Checker"

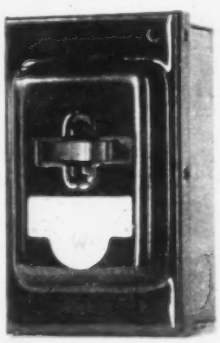
For the production testing, grouping and adjusting of coils and condensers at radio frequencies, new "Type 110A QX-Checker" is said to provide a simple,



dependable method of comparing the *Q*, as well as the *L* or *C* of a radio component, with a given standard. The *Q* of coils is directly read in percentage variation from the given standard, the standard being rated at 100%. As companion instrument of the maker's laboratory "Q-meter," it is intended for use by the production staff and is set to given tolerances for units to be passed. Operated by the usual factory personnel, it is pre-set by the authorized engineer or foreman who has access to the controls within the cabinet. The instrument comprises a power supply, r.f. oscillator (100 kc. to 25 mc.), tuning circuit and specially designed vacuum-tube voltmeter. — *Boonton Radio Corp., Boonton, N. J.*

Midget Switches

For use on oil burners and other applications where midget switches are desired, these new front-operable gen-



eral purpose "type D" safety switches are available in two-pole NEC and plug fuse types, also two- and three-pole solid neutral. Terminals and fuses are accessible. Ample wiring space is provided. Cover may be sealed. Provisions are made for locking switch in "off" position. — *Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.*

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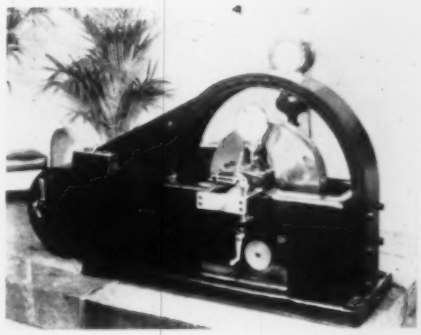

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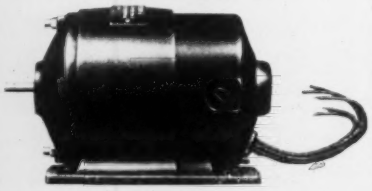

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TYPE I

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1. Conventional Motor mounting interchangeable with most standard self-synchronizing motor elements.
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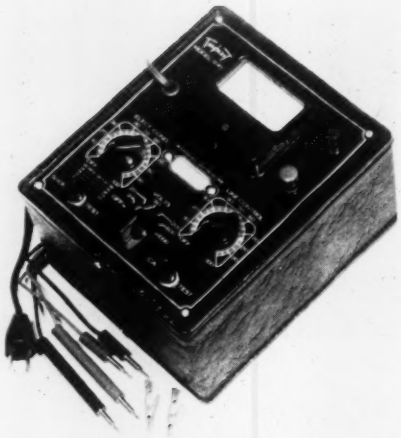
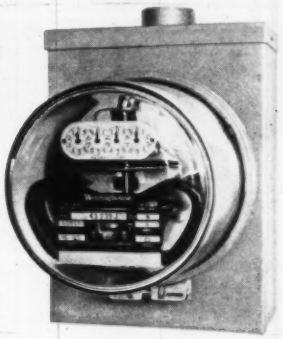


Capacitor Tester

Complete tests of all radio condensers from 0.0001 to 10 μfd—for breakdown, opens, shorts, leakages and capacity—are made with "Model 1240" Master Condenser Tester, and results read directly on the 3" dial. Open condensers and those having high resistance leakages can be determined with certainty. A-c. and d-c. voltages are available for breakdown tests up to 1000 volts in steps of 2, 20, 60, 200, 600 and 1000. It is said that the instrument pointer indicates infinitesimal leakages instantly. For the capacity test, accuracy is maintained by a line voltage regulator with shadow type indicator. There is also a Good-Bad scale for electrolytics. Case is metal with black wrinkle finish, 7⅞" × 6⅝" × 4⅝". Panel is silver and black.—*The Triplett Electrical Instrument Co., Bluffton, Ohio.*

Polyphase Detachable Meters

All of the familiar advantages of the single-phase detachable watthour meter are said to have been retained in a new line of polyphase detachable meters with two complete elements and disks, which may be applied on the same basis as corresponding conventional polyphase meters. "Type CS-2" has four current and four potential terminals for use on all services requiring a two-element meter with transformers. "Type CS-5," which may be used on all 3-wire services which require a self-contained watthour meter, is said to be ideal for 2-phase 3-wire services taken from a 3-phase 4-wire system; also suitable for all self-contained 3-phase 3-wire services. It has four current and two potential terminals. The latter are connected in common and only one of them engages with the terminal in the socket depending upon whether the socket is installed for vertical or horizontal wiring. By using the ring type socket, Type CS-5 meters can be applied to switchboard or other panel mountings. The "CS-7" detachable p... and lighting meter, with seven term... is intended for metering combined ... phase 3-wire power and single-phas... or 3-wire lighting loads taken fro... 3-phase 3-wire delta service where ... phase is tapped to provide single-p... service. (This class of service is so... times classified as "three-phase four-...



delta.") It has two dissimilar electro-magnets. One element has a 2-wire current winding and the other a 3-wire current winding. Both potential coils are wound for 230 volts. The "CS-8," with three current and two potential coils, corresponds to the conventional 2-element 3-current coil, or "2½ element meter" for 3-phase 4-wire services. Like the "CS-7," the "CS-8" has seven terminals and requires sockets having the same terminal arrangements. Among the advantages of these new meters are greater clearances between terminals and consequently greater protection against flash-over failures in the terminal assemblies. This is important where meters are connected without potential transformers on 460- and 575-volt services. Suitable sockets for indoor or outdoor installation are available for each of the new meters. Also, "Type CS-5" is available for use with a "Type A" case.—*Westinghouse Electric & Mfg. Co., East Pittsburgh.*

Air Pressure Regulator

Designed for the sensitive regulation of air pressures <30 lbs./in.², new low-capacity "Type HFS" has a 4" diam. diaphragm which provides a sensitivity approx. six times that of standard type

regulator, the effective diam. of whose diaphragm is generally 1½". Difference between actual regulated pressure and pressure for which regulator is set amounts to 1 oz. variation for each 10 lbs. variation of main line pressure. That is, a variance of 40 lbs. in main line pressure will cause 4 oz. variation in the regulated air pressure. Diaphragm is clamped in regulator body between two brass castings fastened together by radially spaced bolts. Special valve design and construction prevent valve seat from cutting into the rubber valve.—*The De Vilbiss Company, Toledo, Ohio.*

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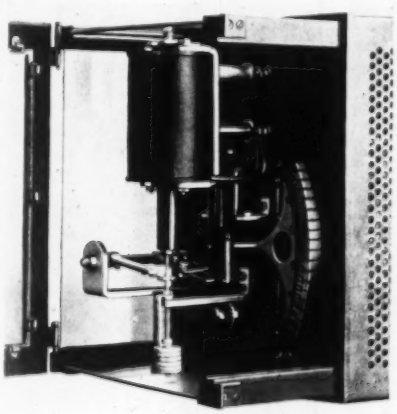
Megohmmeter

"Type 487-A" Megohmmeter applies the simple principle of the ohmmeter to resistance measurements in the megohm range. The requisite sensitivity is obtained by using a vacuum-tube voltmeter as the indicating means. The range is from 20,000 ohms to 50,000 megohms in four overlapping ranges, so chosen that all values of resistance within the normal range of the instrument can be read on the open portion of the scale. The accuracy is 5% between 200,000 ohms and 5000 megohms, decreasing for higher and lower values. Power is obtained from a 115-volt, 42- to 60-cycle a-c. line. There is no danger of shock from exposed test terminals, for their internal output impedance is never <1 megohm and may be 10 or 1000 megohms. Applications include not only the rapid measurement of high resistance, but the measurement of many conditions resulting in resistance changes, such as moisture or adulterant content. Dimensions: 10" × 8" × 5½" over-all. Net weight: 9¼ lbs. — *General Radio Co., 30 State St., Cambridge, Mass.*

Rocking-contact Regulator

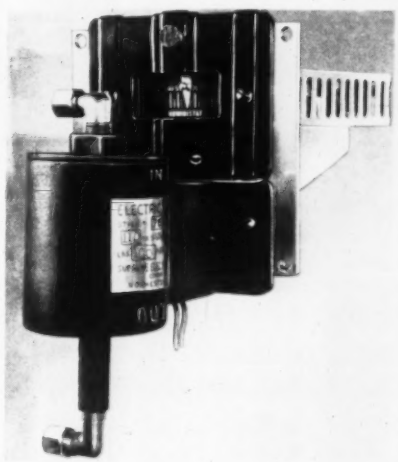
Primarily developed for the automatic voltage control of small a-c. generators, but equally effective for industrial automatic-control applications (speed, current, tension of strips between rolls, etc.), new "Type V-1" regulator employs the rocking-contact principle of altering a resistance with minimal work. Its primary element, responding to changes in



the voltage (or other condition) to be controlled, is a solenoid. This element positions the sector of the rocking-contact rheostat through the agency of a main shaft to which a dashpot is also mechanically connected, but a recall spring is interposed between dashpot and main shaft—these elements therefore constituting an anti-hunting system of automatic control. For the control of a-c. generator voltage, the standard "Type V-1" (illustrated) incorporates a series resistor and voltage-adjusting rheostat which are in the circuit to the potential transformer where bus-bar voltage is taken off. This adjusting rheostat permits the regulator setting to be changed 6% above or below the factory setting. The regulating resistors are selected to conform to characteristics given to makers by mfrs. of each generator and exciter to be controlled in each individual application. A change-over switch, provided for connecting the regulator in the exciter field circuit, affords a means of placing generator unit under automatic or manual control by operator using exciter field rheostat. — *Allis-Chalmers Mfg. Co., Milwaukee, Wis.*

Insertion Humidistat With Solenoid Water Valve

For use in the air-conditioning field, a simplified humidity control consists of a "Supreme" solenoid water valve mounted on a Friez insertion humidistat. Advantages are said to be secured by



combining these two items into one unit. The insertion humidistat is often preferred for installation in cold-air returns and cabinet-type conditioners. Especially in large installations the insertion mounting humidistat provides a better average humidity than can be secured from a wall-mounted instrument. The electric valve, especially designed for humidity applications, has a cast iron case with terminal chamber for BX connections. Installation is simplified; and the costs reduced, as only one electrical connection is necessary for the combined unit. — *Supreme Electric Products Corp., Rochester, N. Y.*

20 mm. or 0.5 μ
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Electric Vacuum Gauge
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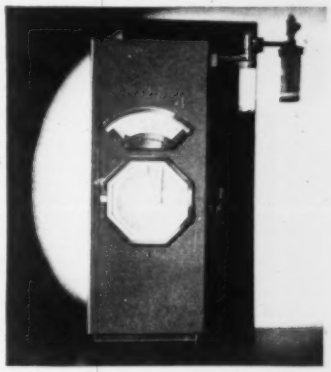

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The redesigned Republic CO_2 Meter incorporates the following important features:

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- The Republic Meter is driven by a fractional horse power motor and no water is required for its operation.
- A filter in the gas line removes all SO_2 before it reaches the meter.
- The large caustic tank holds enough potash to last from 4 to 6 months.
- The simplicity of the meter and its rugged construction eliminates the necessity for frequent servicing and adjusting.
- Hundreds of companies have used the Republic CO_2 Meter for many years and recognize it as standard for the mechanical measurement of CO_2.

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Multi-purpose Wide-adjustment Control Unit

Though belonging to the well-known fluid relay class of automatic controllers (air- or water-operated) and consisting of familiar elements, the "Arca Universal Controller" employs these elements in novel ways both individually and together to achieve a range of applicability said to be far beyond that heretofore associated with the fluid-relay class. For example, in the field of pressure control, instead of a graded series of models, some for low pressures and some for high pressures, there is but one controller, applicable not only to all pressures but to all vacuum-control applications. In addition, it may serve to control large or small flow-rates, and other conditions, without requiring any structural changes. Moreover, it is regularly made up with two bellows, the "second" of which may be used in either of two ways: (1) to make the controller as a whole respond to the difference between two instantaneous values as in flow control or to their sum; or (2) to serve as an anti-hunting follow-up. This "second" bellows, of course, is either one, the selection being governed by application factors.

Fig. 1

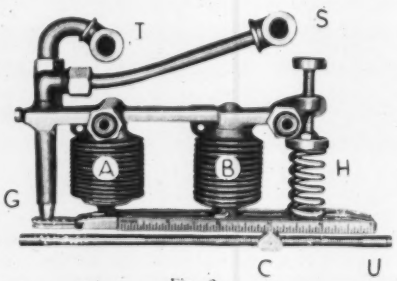

Fig. 2

Fig. 2 shows control unit removed from case and stripped of its four gages. Fulcrum *C* is shown as usually placed for a pressure-control application, its exact position adjusted (from outside of case) by using a screw-driver at *U*; for most vacuum-control applications, fulcrum *C* is placed to the right of spring *H*; for most flow-control applications *C* is placed between *A* and *B*. For applications where either *A* or *B* is below atmospheric pressure (or where both are) maker provides bellows enclosed in boxes, giving direct action. However, standard bellows are preferably used for vacuum in some cases; there are four distinct classes of applications with regard to either or both *A* and *B* being above or below atmospheric pressure, and the choice of free or compensated action gives eight possibilities; but since there are three zones for the fulcrum the total number of combinations is twenty-four. Of these, of course, need be considered as solutions of any specific industrial automatic-control problem.

Adjustments.—Principal initial adjustment is fine adjustment of fulcrum position by means of *U*. Tension of spring *H* can likewise be adjusted from outside of case by unscrewing cap (seen in Fig. 1) and inserting screw-driver. Another overall characteristic is adjusted by regulating the flow of compressed air (or water) to nozzle *G*. Each bellows, likewise, is provided with a needle valve to determine its rate of response to changes in the pressure, temperature, etc., which it measures. A pair of stop-screws limits the possible motion of bellows and the maximum leak of operating fluid through nozzle *G*. The flat spring under nozzle *G* may also be adjusted; removing it gives 0.5% sensitivity (in terms of range).

Other features.—To change from compressed air to city water as operating fluid, substitute large-size for small-size nozzle *G* and screw drain pipe into drain connection at bottom of case. Case is gasketed and all working parts, gages, etc., are of materials suitable for hydraulic as well as pneumatic systems. Cleansing pins, arranged in the nozzle tube and in the passages to both bellows, automatically remove dirt particles from nozzle and from adjustable bellows orifices. With standard spring regularly furnished, an "Arca Universal" unit was satisfactorily used to control a pressure of 250 lbs./in.^{2} using bellows *B* and then a pressure of 1 oz./in.^{2} using bellows *A*. However, a choice of four other springs is offered, as well as special bellows for unusual applications, and gages calibrated for any requirement. By initially selecting suitable gages, one unit can be used successively on a number of temporary automatic-control applications such as those in an experimental department or engineering laboratory, or it can be tried out successively on a number of applications reported to be controllable only by human operators, or it can be installed on one such "difficult" application and from time to time altered in characteristics until—sooner or later—a mode of control is found which the human operator cannot approach.—*Arca Regulators, Inc., 111 Orange St., Bloomfield, N. J.*

Panel Instruments

Two new lines of panel instruments are announced: round (illustrated) and rectangular, but each including the same series of instruments, the bodies being identical. Both round and rectangular types require 2¾" diameter holes for mounting; hence are interchangeable. Movements are of new design, with natural sapphire jewel bearings, shock-proof Bakelite zero adjuster and other features. Accuracy is 2% (rectifier types 5%). Each line comprises twelve different types, each in all ranges in demand, so that total number of models is 114 in the round form and 114 in the rectangular form.—*Simpson Electric Co., 5216 W. Kinzie St., Chicago, Ill.*

Photoelectric Photometers and Colorimeters*

By KASSON S. GIBSON
Chief, Colorimetry Section, National Bureau of Standards

INTRODUCTION

RECENT developments in the barrier-layer type of photoelectric cell have led to the design and manufacture of photoelectric instruments advertised as "colorimeters," color matchers, color comparators, or color "analyzers," as well as others advertised under trade names which include "color" as an integral part.

Several similar instruments are advertised to measure transmission, reflectance, opacity, turbidity, or other similar properties; and in some cases extend their range of application by the use of selective spectral filters.

In addition, there are similar instruments employing the electron-emission type of cell (requiring an external voltage supply) but otherwise similar in purpose and scope to those noted above.

It is the purpose of this article to point out some advantages and limitations of these photoelectric instruments. The discussion will not include the subject of spectrophotometers, except as some of the instruments noted may be considered as abridged spectrophotometers.

Here at last is that authoritative article on using photocells for light and color measurements, requested by many readers. Dr. Gibson discusses the four classes of measurements, the various types of instruments and the sources of error.—Editor

For general information regarding colorimetry and spectrophotometry, the reader should consult references 1-8.

It is generally recognized that accurate spectrophotometric data plus adequate colorimetric computations comprise the most fundamental of all colorimetric specifications. With most spectrophotometers, however, the obtaining of such data and specifications requires considerable time. It is because of their relative speed and simplicity of operation, combined with the fact that fundamental data and specifications are often not needed, that the photoelectric "colorimeters" have such an appeal. Their primary purpose is in most cases to obtain, by photoelectric methods, data which will agree with similar data obtained visually or which will correlate with the results of visual grading. This is obviously true of most instruments claimed to give a measurement of color; it is likewise true of those instruments designed to measure illumination, reflectance, opacity, and turbidity, for there would be little interest in the readings so obtained if they were not thought to agree, at least approximately, with corresponding visual determinations.

Why then is it desired to "eliminate the human eye," if it is, after all, visual values which are sought? The reason is, of course, that photoelectric instruments can be made to operate with greater speed and precision and are less tedious to use in routine work than similar visual instruments.

These advantages are considerable and if reliable results are at the same time obtainable the instrument becomes a useful tool for testing and quality control work.

It is, therefore, of importance to note the various factors affecting results. For the reader's convenience these factors will be discussed under five headings, the first four sections being devoted to distinct fields of application, and the last section dealing with sources of error in any type of instrument.

1. Luminous measurements in which "color" plays a minor part;
2. Application of photocells with spectral filters in abridged spectrophotometry.
3. Photoelectric devices for quantitative chemical analyses.
4. Photoelectric "colorimetry."
5. Miscellaneous factors affecting the reliability of photoelectric measurements related to color.

1. USE OF PHOTOELECTRIC CELLS TO DETERMINE LUMINOUS INTENSITIES, REFLECTANCES, ETC.

Illumination, luminous reflectance, opacity, turbidity, etc., are associated with the brilliance of the light or the lightness of the color, but not with chromaticity. Visually, they depend upon the operation of the so called spectral visibility (luminous efficiency) curve of the human eye, but not upon the chromatic sense of the observer. This visibility curve expresses the relation between light and energy throughout the visible spectrum, the visibility of energy being a maximum in the yellow-green and becoming zero in the ultraviolet and infra red parts of the spectrum. When radiant energy enters the eye it is automatically weighted according to the visibility curve. The observer is unable, however, to assign any but the crudest absolute value to this visibility weighted energy, which is called light or luminous energy. Nevertheless, by the usual photometric procedure, which by necessity employs a null method, he is able to determine relative intensities with considerable precision if they are of the same chromaticity and with less precision if they are of different chromaticities.

The visibility curves of any two observers may differ notably in relative value through the spectrum[9]. When,

*Publication approved by the Director of the National Bureau of Standards of the U. S. Department of Commerce.

[1] Optical Society of America Committee on Colorimetry, L. T. Troland, Chairman, Report for 1920-21, *Journal of Optical Society of America and Review of Scientific Instruments*, Vol. 6, 1922, pages 527-596.

[2] Deane B. Judd, The 1931 I.C.I. Standard Observer and Coördinate System for Colorimetry, *Journal of Optical Society of America*, Vol. 23, 1933, pages 359-374.

[3] Report of Committee on Colorimetry, Optical Society of America, L. A. Jones, Chairman, Eastman Kodak Company, Rochester, N. Y. (In preparation.)

[4] Arthur C. Hardy, Handbook of Colorimetry, The Technology Press, Cambridge, Mass., 1936.

[5] Optical Society of America Committee on Spectrophotometry, K. S. Gibson, Chairman, Report for 1922-23, *Journal of Optical Society of America*, Vol. 10, 1925, pages 169-241.

[6] K. S. Gibson, The Use of the Photoelectric Cell in Spectrophotometers, Photoelectric Cells and Their Applications (The Physical and Optical Societies, London, 1930; also obtainable from Adam Hilger, Ltd., London), pages 157-173.

[7] H. E. Ives and E. F. Kingsbury, The Applicability of Photoelectric Cells to Colorimetry, *Journal of Optical Society of America*, Vol. 21, 1931, pages 541-563.

[8] K. S. Gibson, Visual Spectrophotometry, *Journal of Optical Society of America*, Vol. 24, 1934, pages 234-249.

[9] See, for example, the composite plot of the visibility curves of 125 individuals, published by Coblentz and Emerson in *Bureau of Standards Scientific Paper* No. 303, 1917, Fig. 18.

therefore, the relative intensities of two lights of differing relative spectral energy distribution are measured (even by the relatively precise method of flicker photometry) different values will be obtained by different observers. The variances will depend upon:

(1) The differences in spectral energy distribution of the lights compared (see Figs. 1 and 2) and

(2) The differences in spectral visibility among the observers.

These differences among observers are of such importance in photometry that a standard set of visibility data representative of a normal average observer was recommended by the International Commission on Illumination in 1924[10] and has been in use since then. *Only by the use of some such defining set of data can we give an immediate unambiguous answer* to the problem of the relative luminous intensities of two lights of differing chromaticity or of the luminous reflectance of a chromatic surface.

Now the point to this is that the spectral response curves of the various types of photoelectric cells differ among themselves and do not coincide with the standard visibility curve, as is illustrated in Fig. 3. In general, therefore, the values obtained with photoelectric cells will not agree with the values derived on the basis of the standard visibility data. The extent of departure from such standard visual values will depend on the same two factors that generally make visual values obtained by any single observer differ from the standard visual values:

(1) Departure of the various spectral response curves of the detectors from the standard visibility curve, and

(2) Relative spectral selectivity in the lights compared.

The importance of either factor depends upon the other, as is shown in the following discussion, where the importance of the two factors is considered in turn.

(1) If the spectral response curve of a given cell duplicated the standard visibility curve exactly, being thereby zero in the ultraviolet and infra-red parts of the spectrum, it would always give correct luminous values regardless of selectivity in the luminous intensities compared. No such cell is available. It is, therefore, a question of the degree of approximation of the cell's response curve to the visibility curve. These response curves can be obtained from the manufacturers of the cells, along with other detailed information regarding their operating characteristics[11]. If the spectral response of the cell differs widely from the standard visibility curve, the cell should not be used to measure the luminous values of lights or objects differing considerably in spectral selectivity. In some cases, however, the response curve approximates the visibility curve sufficiently for the user's purpose; or a filter is used which converts the response to an approximation of the visibility curve. Even with close approximation, large errors may result if one attempts to measure the luminous transmissions or reflectances of highly selective materials. The same reasons that made it necessary to establish a standard visibility curve for unambiguous measurements of lights of different chromaticities, make the use of photoelectric cells, even with a visibility filter, unsuitable for such measurements, unless careful tests with a particular cell and filter show this combination to be suitable for the purpose.

[10] The values adopted by the I.C.I. were those recommended by Gibson and Tyndall (*Bureau of Standards Scientific Paper* No. 475, 1923, Table 3, last column) as a result of measurements by themselves and previous investigators on a total of about 200 individual observers.

[11] It should be remembered, however, that a curve so supplied is merely representative of the *type* of cell and that the spectral response may differ considerably from one cell to another of the same make. Unless the particular cell has been subjected to individual test the values supplied by the manufacturer or dealer will not, except by accident, apply exactly to the cell purchased.

Fig. 1. Various spectral energy distributions. I.C.I. illuminants A and C are those adopted by the International Commission on Illumination in 1931 as representative of incandescent illuminants and average daylight, respectively. Curve D is actually that for the sun outside the earth's atmosphere, as determined by Abbot, but is known to approximate the relative energy distribution of over-cast sky and of sunlight plus skylight on a horizontal surface. Curve S is also derived from data by Abbot. The curves are arbitrarily made unity near 550mμ.

(2) On the other hand, there are many measurement applications for which photoelectric cells are eminently suitable and where their speed and precision render them greatly superior to the eye. In this field are many kinds of geometrical distribution measurements, such as the measurement of the distribution of intensity about a lamp or lighting fixture, or of the distribution of reflectance at various angles from a surface, where the spectral quality of the light is unchanged throughout. Even here, however, it is doubtless best to use a cell whose response does not deviate too widely from the visibility curve, in order that unsuspected deviations in spectral quality, even though small, may introduce no important error. Likewise, photoelectric cells are useful for measurements of illumination in different parts of a room under a given, constant lighting condition, although in this case one must guard against variations in spectral quality due to variations in colors of the walls, the curtains, etc. Of course, in many such cases, errors of as much as a factor of 2 may not seriously matter, in which case no such care need be exercised. The measurement of the reflectance of samples of nearly constant spectral reflectance, such as white enamels, or of the relative reflectance of two samples of nearly identical selectivity of spectral reflectance, is another field where the photoelectric cell may prove of great usefulness, even though its spectral response differs somewhat from the standard visibility curve. The limit of such usefulness depends on the accuracy desired, on the relative amount of spectral selectivity in the compared samples, and on the deviations of the spectral response of the cell from the standard visibility curve. A cell which was calibrated

to measure illumination from incandescent lights might be seriously in error in its reading for daylight illumination. A cell giving reliable measurements of the reflectance of white enamels might require recalibration for similar measurements of colored enamels; likewise with papers, paints, etc.

2. USE OF PHOTOELECTRIC CELLS WITH SPECTRAL FILTERS IN ABRIDGED SPECTROPHOTOMETRY.

The usefulness of photoelectric instruments is often greatly extended by the use of filters which limit the spectral range of radiant energy incident upon the cell. The use of such filters, one after the other, affords a crude spectrophotometric analysis, similar to that obtained when a corresponding visual instrument is used with similar filters for the same purpose. Filters often used for this purpose are red, green, and blue, and because three stimuli in additive combination are, in general, necessary and sufficient to produce and specify a color and because the stimuli often chosen produce red, green, and blue colors taken separately, it has apparently been assumed that the use of any three such filters would entitle a photoelectric instrument to be called a colorimeter. This is not true, and the necessary conditions to be fulfilled before an instrument may legitimately be called a colorimeter[12] are discussed in Section 4. In the present section will be considered the use of photoelectric instruments with selected filters as abridged spectrophotometers.

In a true spectrophotometer one is enabled by means of a prism and slits to isolate a narrow wave-length band in the spectrum, and with a series of such isolated bands, each of nearly homogeneous energy, to measure relative spectral distributions of incident, transmitted, or reflected energy. Such an analysis yields a spectral transmission or reflectance curve, or a relative spectral energy

[12] This point is noted by J. Guild, The Instrumental side of Colorimetry, *Journal of Scientific Instruments*, Vol. 11, 1934, pages 69-78.

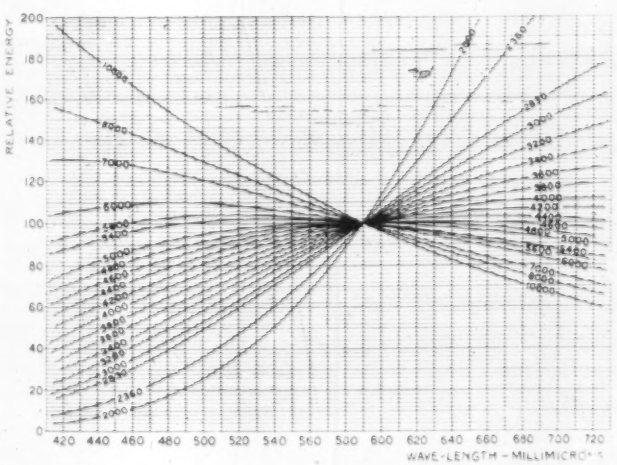

Fig. 2. Spectral energy distributions of the hypothetical Planckian radiator (at various temperatures from 2000 to 10,000° K.) arbitrarily made 100 at 590mμ. Based on Plank's constant (C_2 = 14,350 micron degrees.

These curves closely approximate those for various illuminants: The curve for candle flame is closely approximated by that for 2000°K; the curves for acetylene and vacuum tungsten lamps by those for 2360 to 2450°K; gas-filled tungsten lamps by those for 2700 to 3200°K. Other illuminants are less closely approximated by certain of these curves: The bare carbon arc by the curve for 3800°K; average noon sunlight (Fig. 1) by that for 5000°K; average daylight (Fig. 1) by that for 6500°K; blue sky by that for 10,000°K.

This illustration is taken from a paper by Priest, The Colorimetry and Photometry of Daylight and Incandescent Illuminants by the Method of Rotatory Dispersion, *Journal of Optical Society of America and Review of Scientific Instruments*, Vol. 7, 1923, page 1175.

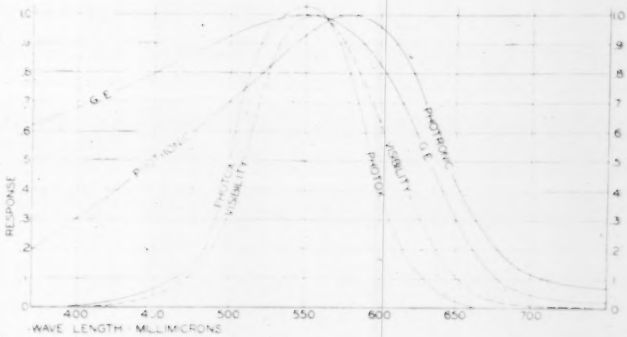

Fig. 3. Spectral response curves of three types of barrier-layer cells compared with that of the eye (the so-called visibility curve). These curves are arbitrarily made unity, or nearly so, at the wave length of maximum response.

This illustration was prepared for the author by R. S. Hunter, Colorimetry Section, NBS.

curve, which (if accurately obtained throughout the whole visible spectrum) affords the only fundamental basis for general colorimetry. Contrary to the case discussed in Section 1, in which the ability of the photoelectric cell to measure luminous intensities was considered, the shape of the spectral response curve of the detector (cell or eye) is of no consequence in spectrophotometry, provided that the response be adequate for the purpose and that suitable precautions be taken to avoid slit-width and stray-light errors.

The slit-width error in spectrophotometry depends on the type of transmission or reflectance curve being measured as well as on the slit-width used[7]. If relatively non-selective samples are being measured the slits may be greatly widened without introducing important errors. But if we widen the slits until they isolate spectral regions comparable to those isolated by filters, we are in effect "using a micrometer where a footrule would do." With certain types of samples, therefore (such as near-white enamels, papers, etc.), it is possible to obtain adequate spectrophotometric analyses by means of a photometer and set of suitable filters, and visual and photoelectric instruments for this type of measurement have been available for years.

It is not amiss to note just what is involved in filter photometry of this type. If the measurement were made without any filter, the value obtained might depend importantly on the spectral response of the cell, as discussed in Section 1, and also on the spectral energy distribution of the illuminant. When the filters are used—placed in turn at some position between the illuminant and the cell—the value obtained in each case may depend not only on these two factors, though to a less extent, but in addition this value will depend importantly on the spectral transmission of the filter and to some extent on the spectral selectivity of whatever is being measured (as noted further below). The instrument may, therefore, be used in two ways:

(1) The operator may have little knowledge of the various spectral characteristics involved. In this case, the instrument may be of value in quality control work. Nothing fundamental will be obtained, but as long as all the various spectral characteristics remain unchanged the values obtained will be comparable from day to day. Unfortunately there is no guarantee of constancy either in cell, illuminant, or filter; any one of the three may change with time, or may be damaged and have to be replaced.

(a) Little is known about the permanency of spectral response of the various types of photoelectric cells; and, as al-

Continued on page 322

Cathode-ray Oscillograph Applications

Seventeenth part of "The Cathode-ray Oscillograph and Its Applications" being published serially in *Instruments*. This series began in the July 19[illegible] issue.

By RALPH R. BATCHER

Radio engineer; cathode-ray and electronic application specialist, Hollis, L. I., N. Y.

WAVE FORM STUDIES[4, 17-21]

While the cathode-ray oscillograph will delineate any applied wave form, the determination of the actual components of this wave generally requires a mathematical analysis, when either quantitative or qualitative information as to the harmonic content is wanted. It is not easy to estimate the number and order of the harmonics and their relative strength by inspection, although there are a few rules that may assist in such studies. The following notes refer to linear time base oscillograms:

1. Low-order odd harmonics produce marked variations from the true sine wave shape, but the resulting curve is still symmetric with respect to the horizontal axis.* A given harmonic may produce either a peaked or a flattened wave, depending upon phase relations, even if relative amplitudes remain unchanged.

2. Higher order odd harmonics usually produce a ripple which is readily apparent (corrugated contour of the sine wave) especially with the seventh harmonic or over.

3. Even harmonics will always produce a curve that is non symmetric with the true axis.*

4. When certain of these corrugations (due to higher-order harmonics) appear in groups that are exaggerated in height over the intermediate ripples, it is found that two higher-order harmonics are present, both of approximately the same order. At certain times, when the two harmonics approach each other in phase, the superimposed ripples are larger. If only one group of these ripples appears per cycle of the fundamental, the two harmonics will have successive orders, such as the fifth and sixth. If two groups of ripples appear per cycle of the fundamental, the harmonics differ by two, as for instance the fifth and seventh.

5. If the actual number of ripples per cycle of fundamental cannot be counted readily, it often is possible to determine the angular difference between successive peaks (dividing the linear time base per cycle into 360 degrees). This might give a clue to the order of the harmonic, or to the average value of the two harmonics when two are present. For instance, what might appear to be an eighth harmonic might in reality be a combination of the seventh and ninth, with the characteristic appearance described under 4.

While these rules may assist in a rough analysis, for more accurate results the curve should be traced or photographed and analyzed directly, using either a graphical or a mathematical analytical method. Individual experience with one particular type of solution will govern the selection of the proper time base to use in such measurements.

[17]Kroncrt. Harmonic Analysis. *Archiv für Technisches Messen*, 1932, V3620, T49.

[18]Kluge. Akustische Messungen. *Archiv für Technisches Messen*, V51-2, Apr. 1934.

[19]Thomas. Delineation of A.c. Wave-forms. *Experimental Wireless and Wireless Engineer*, Vol. 4, 1927, pages 15-23.

[20]Scott. Wave-form Studies with a Cathode-ray Oscillograph. *General Radio Experimenter*, Vol. 7, 1932, No. 1.

[21]Crawford. Photographing Transients with a Cathode-ray Oscillograph. *General Radio Experimenter*, Vol. 8, 1933, No. 12, page 10.

*When a synchronized linear time base oscillator is used the exact time interval during which the "snap back" occurs may not coincide with the true axis referred to here. The latter can always be delineated by temporarily removing the potential of the wave under test from the deflection system, whereby the time base potential remaining on the other set of plates will indicate the position of the axis.

GRAPHICAL ANALYSIS

The actual analysis of a particular wave-form can proceed with either a graphical process or a mathematical one. When only one particular harmonic is present and its order is known, the graphical method is particularly useful. This method is based on the principle that if one cycle of a pure sine wave is divided into a number of equal sections which are then superimposed, the sum of the curves will be zero. Fig. 17 shows a sine wave divided into two sections (A) and into three sections (B), in each case the sum of the superposed portions being equal to zero.

It will be found that if any harmonics are present they will also balance out and will not appear in the resultant curve, *except that harmonic* whose order is equal to the number of sections into which the curve is divided (or to a multiple of this number) thus in the resultant curve all other harmonics will balance out leaving the harmonic at its full amplitude.

As an example if a third and a fifth harmonic is present, the resultant curve will show the amplitude of the third harmonic when the curve is divided into three sections, and the fifth harmonic when it is divided into five sections. If the resultant curve in either case appears sinusoidal it is probable that no higher multiples of the disclosed harmonic are present. A curve with a third harmonic is analyzed in Fig. 17C, the three sections being superimposed at the left.

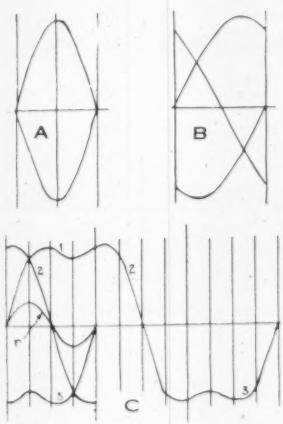

Fig. 17

In applying these principles to a cathode ray analysis the procedure is to use a sweep frequency equal to n times the frequency of the fundamental where n is the order of the harmonic suspected. Record the resulting diagram by tracing or photographing and with dividers add up the ordinates of the superimposed curves to obtain the resultant. It is necessary that the time base be interlocked with the frequency under test. If the resultant is a straight, horizontal line, the *nth* harmonic is absent and another trial with a different value for n should be made. If however the resultant is a sine wave that particular harmonic is present with an amplitude proportional to the ratio of the maximum ordinate of the resultant curve to the maximum ordinate of the [illegible]

Continued on page [illegible]

Oscillography

fifth instalment of "Electrical Measurements and Control." This series began in 1934 (see editorial page of November 1933 issue). All rights reserved by the authors.

By PERRY A. BORDEN and M. F. BEHAR
Member A.I.E.E. Editor, *Instruments*

1. Scope and Definitions

Stated briefly, the subject-matter of this article is (1) the visualizing and (2) the recording, for measurement purposes, of variations in the values of magnitudes when such changes are too rapid to be observed by eye or recorded by any of the types of instruments described in previous articles. In ever-widening fields of electrical measurements and control, the success of new developments, the correctness of installations—and even the outcome of routine tests—depend on the visualization or recording of rapid variations. Various types of instruments have been developed in order to make possible such visualizations or recordings. In general, they are known as oscillographs. Strictly speaking, they may be divided into two groups:

(1) Oscilloscopes, which enable an observer to *see* ("scopeo") rapid variations in values.

(2) Oscillographs, which produce a *permanent record* ("graph") of rapid variations in values.

An oscillogram is the picture obtained by the use of these instruments: it may be a diagram traced by hand on a paper placed over the viewing window of an oscilloscope, but it usually is a photograph—either obtained directly from an oscillograph or taken by placing a separate camera in front of the screen or revolving-mirror viewing device of an oscilloscope.

Since oscilloscopes are convertible into oscillographs whenever cameras are thus used, they are commonly referred to as oscillographs. Moreover, "oscillography" has always denoted this branch of electrical measurements; "oscilloscopy" never; so that it is permissible to use the term "oscillographs" in referring to both groups of instruments as one general category of electrical measuring devices.

Each group had its beginning toward the middle of the nineteenth century—long before the dawn of electrical engineering—in the form of laboratory devices built by French scientists investigating acoustic phenomena, employing diaphragms and other delicate elastic members responding to sound waves. The first "oscilloscopes" were the phonoscopes (still to be seen in physics classrooms) in which the flame of an illuminating-gas burner, fed from the top of a chamber whose bottom was the resonant diaphragm, was viewed in a revolving mirror. The first "oscillographs" were the early French phonographs in which a diaphragm or other responsive element carried a needle which scribed the sound waves on the smoked surface of a revolving drum or on a soft-wax cylinder. We purposely write "oscilloscopes" and "oscillographs" in quotation marks because these phonoscopes and phonographs could not perform any true measurements other than the determination of frequency or pitch; they could not be calibrated (except roughly) in terms of instantaneous level of intensity, and even when they were arduously calibrated for amplitude or peak intensity, the visualized or recorded curves were so distorted that values at points between the maxima had to be guessed at. And we purposely bring up this deficiency in order to emphasize an essential requisite of modern oscillographic instruments: that they be capable of following a measured variable so faithfully that all of its instantaneous values can be measured. Only the types which can do this and are therefore of value to industry will be described in detail.

2. Classes of Applications

Before coming to the instruments themselves, it may not be amiss to touch upon the kinds of measurements which they are expected to perform. In every case, of course, each ultimate numerical reading is obtained by scaling off the distance from a point on the curve to one of the coördinate axes of the oscillogram. This is merely what one does when taking off values from ordinary graphs on coördinate axes, so that the question resolves itself into "what are the forms of oscillograms?"—which really implies "what are the kinds of phenomena for which it is convenient to use oscillographs?"

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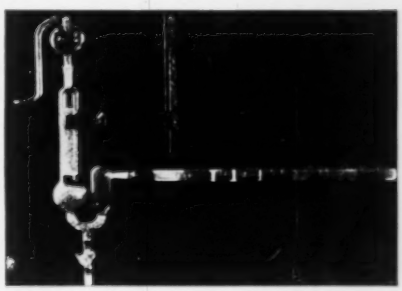

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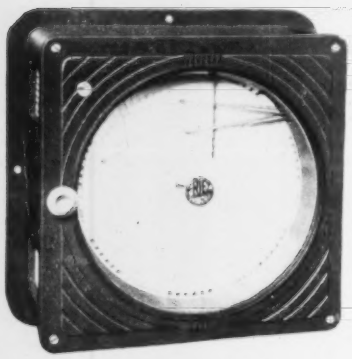

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Rectangular Coördinates

In the great majority of cases it is desired that the phenomenon be represented on rectangular coördinates. All classes of oscillographs have in common, therefore, the ability of thus visualizing or recording the variables under study. Within at least one class, however, there are types and varieties arranged for the production of oscillograms with polar coördinates, 120° triangular coördinates, etc.

I. Of the phenomena which are visualized or recorded on rectangular coördinates, the majority can be represented by simple time records of variations. An oscillograph then merely serves as an ultra-high-speed curve-drawing recorder; and an oscilloscope when thus used presents a picture of the commonest kind of graph: with time for the abscissa and the variable for the ordinates. Within this general category of time-axis oscillographic applications, however, there are two distinct classes:

(a) Regularly recurrent or periodic oscillations such as the alternations of a steady alternating current, the ripples of a rectified current, etc. These can be observed with any oscilloscope capable of making the diagram stand still (as will be explained below) and of course they can be photographed on slow emulsion film or paper because the exposure can be prolonged without blurring. This kind of work is generally known as the determination of wave-form.

(b) Non-recurrent phenomena, such as a surge caused by a lightning stroke, the "kick" on opening a circuit with inductance, etc. These are known as transient phenomena, or simply as "transients" and, since they generally require photographic recording, they require the use of oscillographs. Transients are divided, in turn, into "controlled" and "uncontrolled," the latter requiring special auxiliary apparatus to "trigger off" an oscillograph instantaneously.

Another classification of time-axis oscillographic applications is into:

(a) Those in which only one variable is studied; and

(b) Those calling for simultaneous records of two or more magnitudes. For this class of applications it usually is necessary to use oscillographs rather than oscilloscopes. There are multi-element oscillographs capable of producing a number of parallel records on one film.

II. The other general category of applications calling for rectangular coördinate oscillograms is that in which neither axis represents time. Such applications are growing in industrial importance from year to year, since there are numerous tests of materials and of products which consist in measuring the variations of one characteristic magnitude against those of another. Measurements of magnetic properties, power factor, power, dielectric loss, etc., are thus effected; and double-deflection oscilloscopes have made it possible to employ unskilled labor for the final inspection of magnetic materials, radio receiver capacitors and numerous other quantity-production articles.[1]

Polar Coördinates

In the study of recurrent alternating-current phenomena for analysis of harmonics,[2] and in testing magnetic properties,[3] oscillograms with polar coördinates, or circular oscillograms, are particularly useful. As with rectangular coördinate oscillograms, these may be divided into two distinct classes, according to the inclusion or non-inclusion of *time*. In general, applications requiring true polar-coördinate diagrams do not require a time base; while for applications which are studied by means of circular oscillograms, the circular base represents a definite time cycle.

Triangular Coördinates

Three-phase machines, apparatus and circuits provide the principal applications for the study of which it has been found useful to employ special oscillographs (of the cathode-ray class) with three deflection arrangements 120° apart, each arrangement being in effect a high-speed measuring instrument connected at each phase.

Superposed and Combination Diagrams

Even without employing a multi-element oscillograph, it is possible to commutate the measuring element among two or more circuits under comparative study, thereby visualizing or recording with great convenience the similarities and differences in their characteristics.

[1] Batcher, The Cathode-ray Oscillograph and Its Applications. Instruments Publishing Co. (In preparation.)
Rider, The Cathode-ray Tube at Work. John F. Rider, New York, 1935.
MacGregor-Morris & Henley, Cathode-ray Oscillography. Instruments Publishing Co., Pittsburgh, 1936.

[2] See series of articles by L. W. Chubb & G. H. Cole in *Electric Journal*, Feb.-May 1914, July 1918.

[3] W. R. Woodward & E. L. Furth, Core Loss Testing of Magnetic Materials. *Instruments*, Vol. 7, Sept. 1934, pages 178-179, 181.

3. Classes of Oscillographs

...oretically at least, any principle whereby variations in an electric cur... or voltage may be translated into physical motion may be utilized for the ... of following these variations, provided that the inertia of moving ... be so small as not to distort the results. Mechanical oscillographs have been built, utilizing physical movements, as will later be pointed out. The most important survivor of these in present-day industry is the d'Arsonval type, developed first by Blondel in 1891 and improved by Duddell, and now embodied in several commercial makes.

Any type of oscillograph must include at least two essential parts, (1) A "vibrator" or device for producing motion representative of all changes in the electrical magnitude or magnitudes under investigation; and (2) A device for rendering visible or producing a permanent record of these changes in comparison with a suitable reference axis. In the direct-writing type a pen or stylus is deflected by electromagnetic forces; in the cathode-ray type a thin pencil of electrons is deflected by electrostatic or magnetic forces; in the Kerr cell type a beam of light is interrupted or modified; in the neon-tube type the area of the glow covering the cathode is varied; in all other types the motion is imposed upon a beam of light, generally through the agency of a small mirror attached to the moving part. Recording is generally effected by causing a photographic film to travel perpendicularly to the vibrations of the beam of light. The wave-form of a recurrent phenomenon may be rendered visible in the light-beam types by projecting the light on a moving mirror or screen whereby there are provided the abscissae of the curve whose ordinates are represented by the initial vibrations of the beam. If the movements of the viewing mirror can be synchronized with the fundamental frequency of the recurrent phenomenon it is possible to obtain a definite picture of the wave-form, which may be examined, traced or even measured, without the need of making a photographic record. This, of course, is satisfactory only for periodic or recurrent phenomena; but for studies of transients, photography is usually essential.

The logical classification of oscillographs is based upon the type of vibrator or "galvanometer" which effects the primary response to variations in the measured magnitude and establishes (on the usual time-abscissa diagram) the ordinates of the curve which is to be produced. Such a grouping may be made as follows:

(a) Moving-iron
(b) Moving-conductor
(c) Hot-wire
(d) Electrostatic
(e) Piezoelectric
(f) Cathode-ray
(g) Electrode-glow ("neon-tube")
(h) Kerr-cell

Of these, the first five may be considered as mechanical, in that a definite physical part of the instrument moves, and the other three as electronic or electro-optic. The developments which have taken place in mechanical-type oscillographs in the last few years are for the most part in the nature of improvements in the visualizing and recording attachments, and in devices for rendering the instruments automatic in their action. The cathode-ray oscillograph in its practical form, being a relatively recent arrival, has evolved concurrently with many automatic accessories, so that in its present-day embodiment it is capable of recording to the fraction of a millisecond occurrences which are altogether unpremeditated.

4. Principles of Vibrating Elements

(a) Moving-iron

As originally developed by Blondel, the moving-iron oscillograph is similar in its principle to the "polarized vane" ammeter and voltmeter element of Ayrton and Perry (*Instruments*, March 1934, page 48). It will be understood by reference to Fig. 49-2. Between the poles of a permanent magnet is stretched a thin flat strip of steel S in such a manner that the flux passes along its width. Two coils C, C, carrying the current to be investigated, are placed one on either side of the strip with their common axis perpendicular to both the length of the strip and the main-field, so that the field produced by current in their windings will be perpendicular to that of the magnet. The strip tends to set itself with its width along the resultant field, and thus takes up a torsional vibration representing changes in the current flowing in the coils C, C. A small mirror M, cemented to the strip, serves to superimpose the vibrations on a light beam for recording or viewing.

A modern form of moving-iron oscillograph is shown diagrammatically in Fig. 49-3. Permanent magnets of cobalt alloy supply a steady flux in the four air gaps. When current flows in the coils the flux in one pair of diagonally

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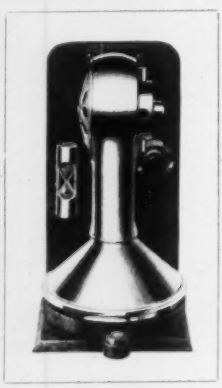

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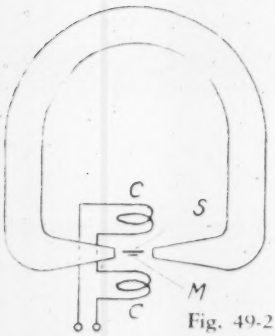

Fig. 49-2

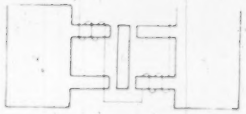
Fig. 49-3

opposite gaps is increased, while the flux in the other pair is decreased, resulting in a force couple which tends to rotate the armature about its vertical axis. The armature structure consists of a steel reed in the form of a cross, and having a ninety-degree twist, so that while the arms of the cross form a part of the magnetic circuit, the stem maintains it centered in the air-gap. The mirror is carried on a short stem extending above the armature.

(b) Electromagnetic Moving-conductor

String Vibrator

The principle of the moving conductor in a magnetic field, similar to that upon which the d'Arsonval galvanometer is based, lends itself admirably to the purposes of oscillography and, while it finds application in a number of forms and makes, may be classified in two groups, the string galvanometer and the loop type. A diagram of the string galvanometer, due to Einthoven (1901) is shown in Fig. 49-4 (Cambridge). It consists in an exceedingly fine fiber CC (frequently silvered quartz) suspended under slight tension in the concentrated field of a strong magnet. The movements of this fibre in response to currents flowing in it are extremely minute but reproduce faithfully all current variations. The optical system includes a microscope inserted in a hole drilled through the magnet poles parallel to the flux direction, and this provides a shadow of the fiber in a concentrated beam of light. The string galvanometer can hardly be called an industrial instrument, as it has found its widest application in the medical field, particularly in the electrocardiograph.*

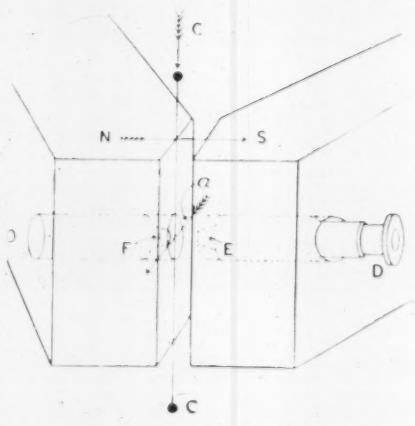

Fig. 49-4

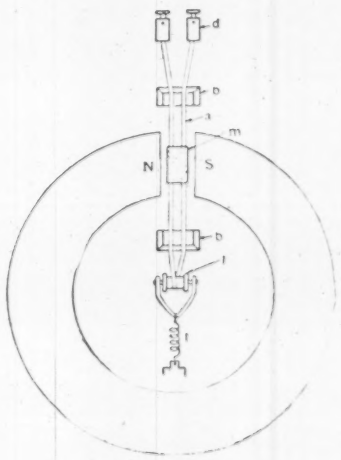

Fig. 49-5

Loop-type Vibrator.

By far the most extensively used type of non-electronic oscillograph is that devised originally by Blondel in 1891, and comprising a single loop of fine wire or ribbon located in the field of a magnet. This type of element is made by various manufacturers, but the principle is essentially the same in all. The construction and operation of the element will be understood by reference to Fig. 49-5 (Westinghouse). In a narrow gap between the poles N, S of

*An instrument widely used in studying delicate potential differences associated with muscle action. The cardiograph has become an indispensable tool in the hands of the diagnostician concerned with heart pathology. Recent developments in vacuum-tube amplifying systems have made practicable the use of more simple forms of oscillographic elements for electrocardiography and have greatly extended the use of the cardiograph by rendering it rugged, portable, and relatively inexpensive.

magnet, which may be either permanent or excited, are stretched two parallel conductors, *a*, formed by bending a thin ribbon of silver alloy back upon itself over a small ivory pulley *p*. A spring, not shown in the figure, serves to maintain a uniform tension on the strips, and guide-pieces *b,b*, similar to the bridge on a violin, limit the length of the free portion to that part actually in the field. A small mirror *m*, bridges across the strips but does not electrically connect them. The effect of passing a current through the loop is to deflect the strips in opposite directions, so that the mirror is turned about a vertical axis.

Representative modern moving-conductor oscillographs will be described in a later section.

(c) Hot-wire

The principle of the hot-wire galvanometer was successfully employed by Irwin in 1907 in an oscillograph which gives satisfactory performance on commercial frequencies. The basic diagram is shown in Fig. 49-6. Conductors W_1 and W_2 are the vibrating filaments. Battery *B* provides a direct current which divides equally between the resistances R_1 and R_2, returning by the filaments. The voltage to be investigated is applied to the terminals T_1 and T_2, including the resistance R_3 in series with the oscillograph network. It will be seen that the currents derived from the source to be investigated will be additive to those from the battery in one of the filaments and subtractive in the other. Thus there is obtained the equivalent of the thermal wattmeter circuit (see *Instruments*, June 1935, page 150) and if the strips W_1 and W_2 have equal resistance the difference in their heating will vary as the voltage across the terminals T_1 and T_2, so long as the battery voltage is maintained constant. A mirror spanning the strips will be angularly deflected in response to their differential expansion, and will superimpose on a light beam vibration representative of the current under investigation. By replacing the battery by an a-c. voltage, this form of element may be used as an *oscillographic wattmeter*. The simple hot-wire oscillograph possesses a degree of temperature lag which limits its use to low frequencies; but Irwin describes a means whereby the lag due to conduction and radiation of heat is compensated for by shunting the resistance R_3 by a suitable condenser *C*.

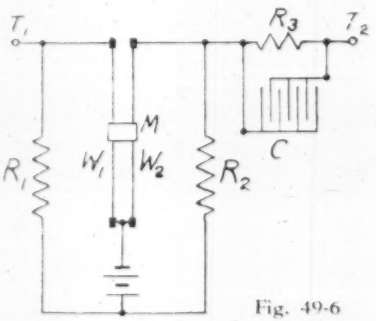

Fig. 49-6

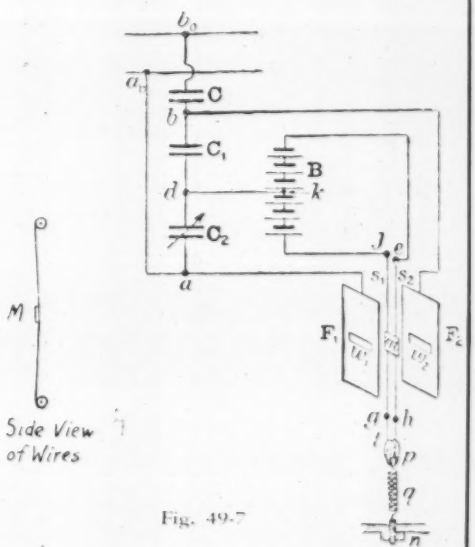

Fig. 49-7

(d) Electrostatic

The element of the electrostatic oscillograph is essentially potential-operated, rather than current-operated, and is particularly suited to investigations of relatively high-voltage phenomena. One form is shown diagrammatically in Fig. 49-7 (Cambridge). Two plates F_1 and F_2 are excited by a definite fraction of the a-c. voltage under investigation, this being obtained by means of a voltage divider made up of a series of condensers *C*, C_1 and C_2, which reduces the potential to a suitable value at the terminals *a* and *b*. Stretched in the space between the plates, and parallel to each other and to the plates, are two fine metal strips, insulated from each other and maintained in tension by a silk thread *t* passing about a pulley *p*, which is attached to a light spring *q*. The

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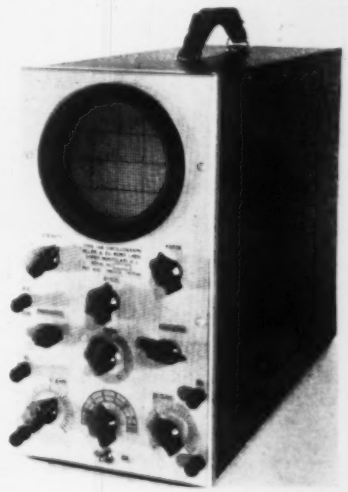

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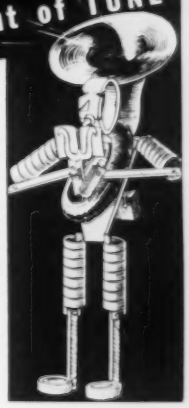

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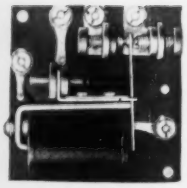

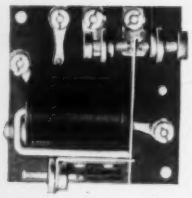

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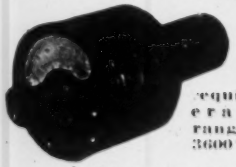

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strips are maintained at a definite potential difference by means of battery having its mid-point connected at *d* to a point between the condensers C_1 and C_2. Upon the application of alternating voltage between the plates F_1 and F_2 the strips, because of their opposed polarities, will be attracted toward opposite plates, with the result that a small mirror *m* attached to them will swing in response to the voltage variations. Light falls upon the mirror through a window w_1 in one of the plates, a similar window w_2 being provided to preserve electrostatic symmetry.

(e) Piezoelectric

The electrification of some natural crystals when stressed along a unitermal axis of symmetry was discovered by J. and P. Curie in 1880, and, the following year, acting on Lippmann's suggestion that they reverse the process, they demonstrated the relation between electrification and changes in size and shape. Oscillographs utilizing the piezoelectric effect do not seem to have been developed until about forty years later. Their chief advantages, obviously, are low cost and simplicity, but each individual crystal element having a natural period (tens or hundreds of kilocycles) it is limited to certain frequency spectra within which it has a flat sensitivity characteristic. In order to oscillate a mirror, the alternating potential is so applied as to *twist* a long crystal carrying the mirror at one end. In modern instruments of this class it is possible to interchange crystal elements to cover all commercial a-c. and audio frequencies. Radio frequencies are too close to the natural periods of most readily available and readily produced crystals. Piezoelectric oscillographs are described in Section 7.

(f) Cathode-ray

Some eighty years ago the beautiful phenomena of electric discharges in partial vacua began to fascinate numerous scientists, and in 1876 the name "cathode rays" was coined by Goldstein, who discovered their *perpendicular emission* and their *deflection* by an electrostatic field, and who demonstrated their *rectilinear propagation* (which Hittorf had observed in 1859), thereby producing the first cathode-ray *instruments*. Many investigators of the dawning electron theory in the nineties refined Goldstein's crude apparatus into the cathode-ray *measuring* instrument and—just before the turn of the century—

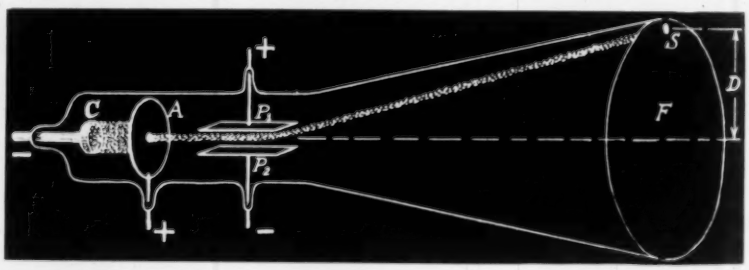

Fig. 49-8

Braun introduced the fluorescent screen which made it into the first cathode ray *oscilloscope*. Fig. 49-8 shows roughly the essentials of an early cathode ray *tube*. Between anode *A* and cathode *C* there is maintained a potential difference of some tens of thousands of volts. The air pressure in the tube being around a few millionths of an atmosphere, electrons are emitted perpendicularly from the surface of the cathode and travel to fluorescent screen *F*, producing a brilliant spot *S* which can be viewed from either side of the screen. The stream of electrons being negatively charged, it may be deflected by the plates P_1P_2 as shown by the signs, the deflection *D* being exactly proportional to the deflecting potential if this potential is constant, if the tube is properly designed and if other conditions are kept constant. Proportionality of alternating deflections remains exactly linear at all commercial frequencies and through the audio spectrum, because the electrons travel at thousands of miles per second. For use at radio frequencies extending to megacycles, modern tubes must have cathode-ray speeds approaching half the speed of light in order to minimize phase error (think of the water jet from an oscillating nozzle). The modern high-speed cathode-ray *oscillograph* dates from 1913 when Dufour first employed the combination of high voltages, high vacua and high-speed photographing—not in a simple tube but in a complicated apparatus.

For the sake of simplicity, only one pair of deflection plates is shown in Fig. 49-8 and the principle of *magnetic deflection* has not been touched upon.

mmon arrangements of two pairs of electrostatic plates will be described in ction 8, as well as magnetic deflection coils, electron-accelerating arrangents and other devices in common use.

Fig. 49-9

(g) Electrode-glow or Neon-tube

The area of the glow covering the cathode of a discharge tube is a function of the current passing through the tube. By using elongated electrodes the *length* of the glow varies with the current, and when a rapidly-alternating current is applied, each electrode glows alternately so that—to the unaided eye both seem to glow continuously (see Fig. 49-9). The tube is viewed in a revolving mirror. Section 9 deals with this class.

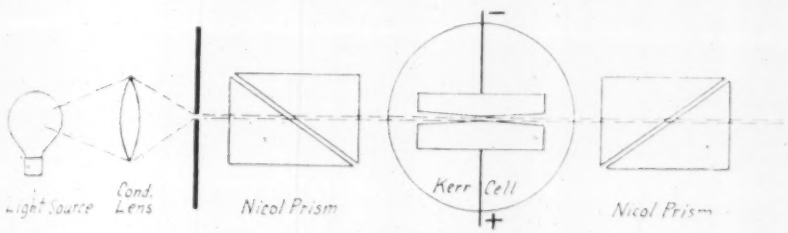

Fig. 49-10

(h) Kerr-cell

When an electric field is established in some substances, they become doubly refracting. (This is the electro-optic effect discovered by Kerr in 1875.) Carbon disulphide is generally used. The capacitor plates are immersed in this liquid. The beam of light passes between them. Fig. 49-10 is a sketch of the essentials. This class is dealt with in Section 10.

To Be Continued

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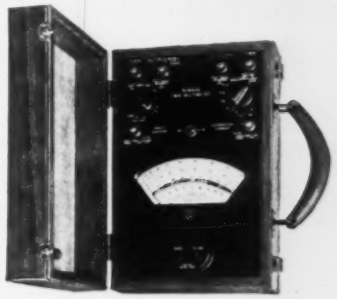

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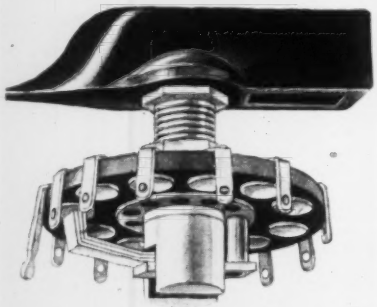

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Precision Pressure Gage

Question No. 1 **Subject Index 2.04**

". . . a precision pressure gage with a range extending from 0.5 to 2.0 lbs./in.²."

A. The *** Department of your own Company could supply from its stock a gage of fair "precision," so we infer that you desire an unquestionable Standard which can be read to 0.0001 lb./in.² and can be used for the calibration of pointer-and-dial instruments. We therefore suggest a six-foot range U-tube manometer, distilled air-free water, and a table of temperature corrections for the differential expansion of the water and of the (brass) scale. Or: A 5" mercurial manometer, with a cathetometer or reading microscopes and other high-precision features. With either the water or mercury type of Standard, a source of clean, dry compressed air, a precision regulator, and an excess-pressure shut-off valve, are usual accessories; but an adjustable mercury column would probably do as the source of constant pressure.

Photocell Output

Question No. 2 **Subject Index 5.3**

*"Can dry self-generating photoelectric cells be made up into dimensions other than reported in your columns? * * * What e.m.f. would be generated by cells of the following dimensions * * *. Could such cells operate relays directly?"*

A. Makers of dry disk photovoltaic cells can supply them in larger sizes than those of their stock models, but for each type of material there is (a) an area beyond which the resistance-output relation makes it preferable to use a plurality of cells rather than one large unit, (b) an optimal size for each common industrial application, and of course (c) an optimal shape: the circle. For the strip which you propose we recommend a row of square cells in close formation; and, if your application requires continuity, we recommend two rows, like this:

As to e.m.f. generated, the *open-circuit* voltage is of the order of a quarter volt for an illumination level of one lumen but this is of little practical interest. The usable *output*, maximal with external resistance matching cell resistance, is of the order of microwatts per lumen for a square-inch cell. Manufacturers issue families of curves giving the microamps. *vs.* lumens or foot-candles for various values of external resistance, and other characteristics. As to relays designed to be operated by photovoltaic cells, there are several makes and numerous models.

Thermocouples

Question No. 3 **Subject Index 2.05**

"We find replacement of rare-metal couples expensive in spite of observing precautions recommended by pyrometer manufacturers. This is no reflection on them, as we have to measure temperatures often exceeding 3000°F. Are there high-melting-point alloys of more common metals (such as tungsten) which have been calibrated so that their e.m.f. curves have been published? For certain reasons we do not desire to switch over to radiation and optical methods."

A.—Tungsten *vs.* molybdenum is a couple that should theoretically produce a usable e.m.f. curve from 2200 F. up to the softening-point of your furnace refractories, and Dr. H. T. Wensel at the Bureau of Standards may be in position to give you some numerical data, but the trouble you will have in welding each junction may represent a greater expense than you are now incurring. Moreover, you will have to protect each couple by a high-grade refractory tube, whereas Pt *vs.* Pt-Rh couples resist oxidation better than any other commercially-available wires. As to your objections to radiation and optical methods, if they spring from the requirement that temperatures must be continuously indicated or recorded on a remote panelboard, we would advise you that such continuous remote recording is practicable with radiation or optical methods, the only absolutely essential installation condition being a sighting-hole and with the new remote-reading optical pyrometers a small quartz window can serve this purpose because it can be kept clean enough to transmit the "color temperature" spectral distribution.

Special Inside Gage

Question No. 4 **Subject Index 2.01**

". . . for reading the inside diameter of curved tubes, from three to four inches in diameter, within 1/100 of an inch. Preferably an electric system whereby the gage head could be pushed into the curved tube and a suitable reading instrument at the end of the tube."

A.—Our records do not show that the special gage which you seek is commercially available. However, there are numerous companies which manufacture suitable indicating instruments for the receiving end, and which could build you a special gage head. Inasmuch as the inside diameters are 3" to 4", we suggest that you consider mechanical and hydraulic gaging systems as well as electrical methods.

With regard to *mechanical* possibilities, the manufacturers of star gages such as are used for accurate measure-

... of bores of rifles and cannon, could possibly supply you with a device consisting of the standard star gage head and of the standard indicator, with a flexible connection between them instead of the standard rigid connection. The flexible connection is made possible by the recent development of flexible shafting with minimal backlash error such as is used between the knobs and the capacitors of automobile radios.

With regard to a *hydraulic* gage, the situation is somewhat different. There are numerous manufacturers of dial indicators wherein the pointer is actuated by a bellows, diaphragm, helix, etc., sensitive to minute volumetric changes; but we have no record that they regularly manufacture transmitting elements in the form of a star gage head, *i.e.*, with three feelers 120° apart. Moreover, for extreme accuracy, a temperature compensator would have to be incorporated in the system.

Electrical systems for gaging dimensions with micrometric accuracy are on the market. The gage heads utilize variable capacitors, variable resistors, variable air gaps in a magnetic circuit, and other principles whereby a minute displacement is converted into a proportional variation in the voltage, current or frequency transmitted to the indicator. Although we have seen numerous special-purpose gage heads, we have not yet seen one resembling a star gage.

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Problem No. 1 Subject Index 2.05

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[This came by air mail from a world-famous sugar refining company. We immediately suggested a shunt-orifice arrangement and supplied names of manufacturers of liquid meters, but it seems that no commercially available device is exactly suitable, and the enormous variation in flow-rate would seem to destroy the effectiveness of any arrangement in which the main flow is metered with the aid of one constriction having a constant discharge area. . . . But do not let *our* discussion throw your imagination off the right track!]

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MEASUREMENT TECHNOLOGY (1)
Measurement Theory (Definitions, systems of units, dimensional analysis, etc.) (1.1)
Measurement Practice (Calibration, etc.) (1.2)
Calculation (1.3)

MEASUREMENT and CONTROL TECHNIQUE (2)
(Applications not confined to any one industry or branch of engineering.)
Length, Angle, and Area (2.01)
Time, Speed, and Acceleration (2.02)
Weight, Density, and Specific Gravity (2.03)
Pressure and Vacuum (2.04)
Flow and Volume (2.05)
Temperature (2.06)
Heat and Combustion (2.07)
Humidity and Moisture (2.08)
Power, Work, and Output (2.09)
Physical Properties. (Viscosity, hardness, elasticity, plasticity, surface tension, etc.) (2.10)
Liquid Level (2.11)

TESTING and INSPECTION (3)
Laboratory Testing and Inspection (3.1)
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ELECTRICITY and MAGNETISM (4)
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Electrical Measuring Devices and Applications (4.2)
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ELECTRONICS and RADIO (5)
Radio Measurements (5.1)
Application of Radio-frequency Principles (5.2)
Photoelectric Measurements and Applications (5.3)
Electronic Measurements and Applications (5.4)

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LIGHT, OPTICS, and RAYS (7)
Light—General (7.1)
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Photometry (7.3)
Polarimetry (7.4)
Spectrometry (7.5)
Photography (7.6)
Microscopy (7.7)
Electromagnetic Rays (other than visible light) (7.8)
Cathode Rays, Positive Rays, etc. (7.9)

CHEMISTRY (8)

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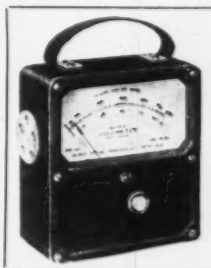

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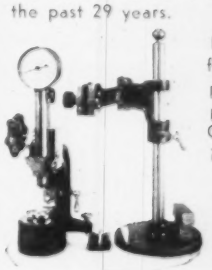

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Cathode-ray Oscillograph Applications

Continued from page 312

corded oscillogram. If the resultant is a straight horizontal line displaced from the axis, either a d.c. is present in the wave, or else the wrong location for the X axis was used.

For a rough preliminary analysis it is necessary to sum up the curves along *only one* ordinate, and this may be done with measurements directly on the screen. If they add up to zero along any line drawn at random normal to the horizontal axis, the test can proceed to the next harmonic. In all of these tests, of course, distances below the horizontal axis are given negative values while distances above this axis are positive. When certain harmonics are indicated a more complete and accurate test can then be made.

In this way less photographs are necessary and the actual computations will be less tedious. If desired one cycle of the wave form can be photographed and copies can be divided off into various numbers of segments and analyzed in the same way. When a harmonic is discovered the position where the resultant curve crossed the horizontal axis with respect to the main curve (or a corrected curve with the harmonic subtracted) will indicate the relative phase difference between fundamental and harmonic.

MATHEMATICAL METHODS

In contrast with the above graphical method, a large number of mathematical processes have been described, in which the heights of a certain number of spaced ordinates are substituted in a formula.

The greater the number of the equi-spaced ordinates used, the greater the accuracy and the higher the harmonics that can be determined, but the mathematical work becomes more tedious. Since many such systems have been repeatedly published, it is not necessary to

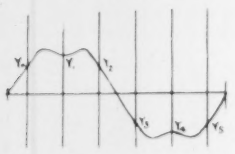


Fig. 18

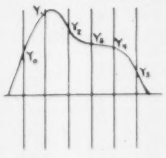


Fig. 19

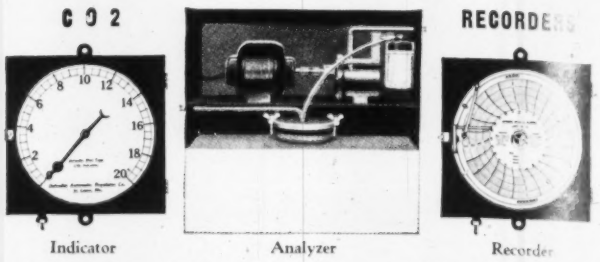
take up other variations here. The following is based upon dividing one cycle of the curve into six sections (about the minimum number that can be used). Designate the values of the six ordinates y_0 *to* y_5 (Fig. 18).

$$y = A_0 - A_1 \cos x + A_2 \cos 2x + A_3 \cos 3x + B_1 \sin x + B_2 \sin 2x$$

The values of the coefficients can be found:

$$A_0 = 1/6\,[y_0 + y_1 + y_2 + y_3 + y_4 + y_5]$$
$$A_1 = 1/3\,[y_0 - y_3] + 1/6\,[y_1 + y_5 - y_2 - y_4]$$
$$A_2 = 1/3\,[y_0 + y_3] - 1/6\,[y_1 + y_2 + y_4 + y_5]$$
$$A_3 = 1/6\,[y_0 - y_3] - 1/6\,[y_1 - y_2 - y_4 + y_5]$$
$$B_1 = \frac{1}{2\sqrt{3}}\,[y_1 - y_5 + y_2 - y_4]$$
$$B_2 = \frac{1}{2\sqrt{3}}\,[y_1 - y_5 - y_2 + y_4]$$

When an adjustable linear time base oscillator is used, the timing frequency can be set at six times that of the measured wave, whereby the wave is automatically divided into six equal sections. The required values can then be measured along *any* line drawn vertically through the diagram, or at either edge, but care must be exercised to correctly label the values in their true order consecutively. The diagram in this case corresponds somewhat to Fig. 17A.



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This method of dividing up the oscillogram into a given number of equal divisions by adjusting the timing base to the desired multiple frequency is more accurate than dividing up the fundamental wave by measurements, since any non-linearity of the timing base prevents the accurate location of the ordinates in the latter case.

If inspection shows that even harmonics are absent, an accurate study can be made using only one half-cycle of the recorded oscillogram. This half-period is likewise divided into six sections, as in Fig. 19.

If we let $y = A_1 \cos x + A_3 \cos 3x + A_5 \cos 5x + B_1 \sin x + B_3 \sin 3x + B_5 \sin 5x$. If we start where the curve crosses the X axis so that $y_0 = 0$, then—

$$A_1 = 1/6\,[y_2 - y_4] + 0.289\,[y_1 - y_5]$$
$$A_3 = 1/3\,[y_4 - y_2]$$
$$A_5 = 1/6\,[y_2 - y_4] - 0.289\,[y_1 - y_5]$$
$$B_1 = 1/6\,[y_1 + y_5] + 0.289\,[y_2 + y_4] + 1/3\,[y_3]$$
$$B_3 = 1/3\,[y_1 - y_3 + y_5]$$
$$B_5 = 1/6\,[y_1 + y_5] - 0.289\,[y_2 + y_4] + 1/3\,[y_3]$$

The student is fortunate who has access to equipment for building up known complex wave-forms synthetically so as to get experience in recognizing the effects of the phase and order of the harmonics. *To Be Continued*

Photoelectric Photometers and Colorimeters

Continued from page 311

ready noted, there may be considerable variations from one cell to another.

(b) The ordinary tungsten-filament lamps become yellower with use, due to deposit of tungsten on the inside of the bulb, and different lamps may have widely differing normal operating characteristics, though different lamps of the same type usually differ but slightly.

(c) Most glass filters are satisfactorily stable in the visible spectrum with ordinary usage, and dyed gelatine filters somewhat less so. In case of loss or damage, however, it is difficult to get an exact duplicate; this is particularly true of a glass filter from a different melt than the original.

The net result of all this is that there always is some doubt whether results today are comparable with those obtained a few weeks or a few months back; this is especially true where replacements of the above-listed items have been necessary. A partial remedy for this situation is possible if one has available a reliable control sample with which to test the instrument.

(2) If the various spectral characteristics of the instrument are known, the measurements made will be of permanent value. For many materials they will afford a sufficient spectrophotometric analysis, the values being plotted as a function of wave-length[13] as for regular spectrophotometric data. *To be concluded*

[13] For methods of computing this wave length see Photoelectric Colorimeters," *Bureau of Standards Letter Circular LC-473*, 1936, pp. 7-8.

INSTRUMENTS' BOOK SHELF

Electronics and Electron Tubes. By E. E. McArthur. John Wiley & Sons, New York, 1936. Fabrikoid, 6 × 9¼ inches, viii + 173 pages. Price $2.50.

There have appeared excellent theoretical texts on electronics; there have appeared compendious handbooks on electron tubes; there have appeared practical handbooks on electron-tube applications. To the best of the reviewer's knowledge, however, this is the first book on electron tubes written especially for engineers and research men in industry rather than for university students or for specialists in the applications of electron tubes. It seems to have been written for the busy man who neither wants to memorize formulas for an examination nor cares for detailed circuit diagrams of radio, television and industrial applications; the man such as the chances are ten to one that *you* are. It is brief, but in the first 40-odd pages of large type the author succeeds in describing the fundamental principles which underlie the action of all electron tubes, after which, in 100-odd more pages, he manages to describe the functioning of the most important forms of tubes.

Chapter I, though entitled "Electrons, Atoms, Molecules," impresses on the reader's mind the atomicity of electricity and the electron-drift nature of a current in a conductor. Chapter II, though entitled "Properties of Gases," deals mostly with ionization phenomena. Unassumingly entitled "Elements of Electron Tubes," Chapter III is a delightfully readable account of the principal phenomena which take place at the surface of the cathode and between the cathode and anode, concluding logically with an eight-page section on space-charge effects—a little gem of scientific exposition. It unfortunately is marred by a glaring example of slipshod editing: the text refers to potential-distribution curves *a*, *b*, *c*, *d* and *e* in Fig. 14, but this figure lacks curve *c* representing the true potential gradient. (However, so well does the author explain the space-charge effects that the reader can almost draw curve *c* for himself or can consider it to coincide with curve *d* for all practical purposes. Elsewhere, as on page 10 where we find "300°K or 23°C," the errors are less serious.)

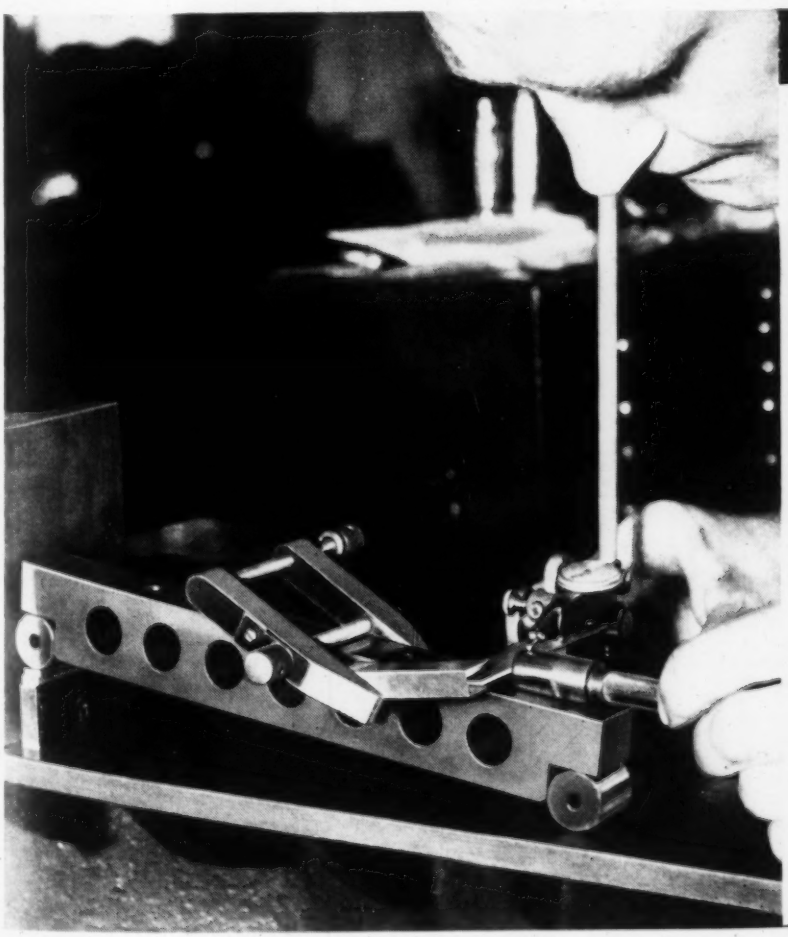
The same plan, of describing underlying principles rather than going into design and construction details, is followed in the next five chapters, on diodes, on grids and magnetic control, on principles of application of triodes and multi-grid tubes, on gas-filled tubes, and on the principles of control by means of gas-filled tubes.

It is only in the last two chapters, on special-purpose tubes, and on construction of electron tubes, that the author has made brevity his only aim, and the result is thirteen pages that should either be omitted from future editions or expanded for the sake of fact-seeking readers.

Except in these last two "chapters" the author succeeds in presenting an impressive mass of information in usefully quantitative terms, yet with a minimum of mathematics. Being in the employ of the General Electric Co. at Schenectady, he has no doubt gained much of his own knowledge from Dushman, Hull and other G-E Research Laboratory physicists who usually express themselves mathematically, but he works in the company's Vacuum Tube Engineering Department where the trees of research are made to bear saleable fruits, and this probably gave him the initial opportunity of writing a series of readable articles for the *General Electric Review*, of which the present book represents an elaboration. But there are mighty few engineers who can even "translate the Dushman mathematical expositions into words and curves for the benefit of their fellow-engineers," and E. E. McArthur the writer deserves as much commendation as E. E. McArthur the disciple. (Perhaps we should apologize to Dr. Dushman, who writes and lectures fascinatingly in non-mathematical terms . . . fascinatingly but all too infrequently!) Particularly commendable is McArthur's combination of thoughtfulness in explaining each electronic term the first time he uses it, together with his *not* explaining general physical terms known to all engineers. Commendable, too, is the careful planning of his book (except for the last two "chapters") as an orderly home-study course, in which the first three chapters might be called "general principles" and the next five chapters "specific principles of operation and application." This planning is evident at first glance in various corresponding diagrams and families of curves, and it becomes more evident in corresponding portions of the text. Such planning is necessary, of course, in any mathematical treatment of a branch of physics, but we repeat that this book is essentially non-mathematical.

We must repeat also that the treatment is reasonably quantitative: all essential formulas are stated, and numerous curves as well as several tables permit the user of electron-tube devices to obtain some numerical values when using this book as an aid to the solution of problems met with in actual practice. (Unfortunately, units are not always clearly stated. On pages 12-13, for example, there is not the slightest hint as to what "unit area" means.) Of course this is not a handbook, so the reader must not expect to find those long tables of tube characteristics issued by manufacturers. But on the whole, it's ten to one that you who read *Instruments* will find this book to be exactly what its title leads you to hope that it will be.

M. F. Behar (5.4)-B-



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